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# An Evaluation of an Airborne Laser Profiling System for High Precision Terrain Mapping

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This report presents the results of an evaluation of the capabilities of an airborne laser profile system to obtain "ground truth" data for the evaluation of the range tracking capability of high resolution radar altimeters. Quantitative evaluations were made of man-made objects such as seats/steps at a football stadium and various buildings. Qualitative evaluations were made with natural terrain such as trees, lakes, land elevations, and power lines along a trackline over Florida.

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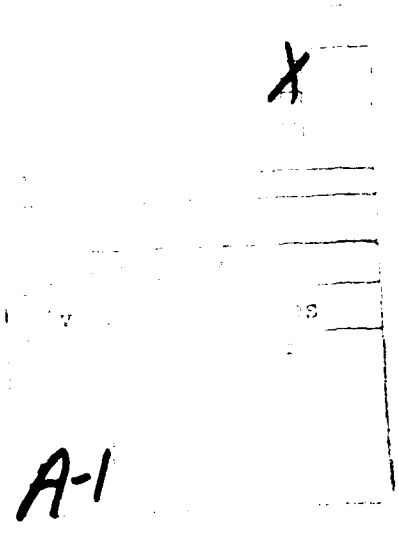

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# AN EVALUATION OF AN AIRBORNE LASER PROFILING SYSTEM FOR HIGH PRECISION TERRAIN MAPPING

## I. Introduction

The Space Sensing Branch, Space Systems Technology Department, of the Naval Research Laboratory (NRL), has been using an Airborne Laser Profiling System to map various types of terrain.

The objectives were: 1) to evaluate the hardware and software capability of the airborne laser profiling system, the Global Positioning System (GPS), the Inertial Navigation System (INS) and the aircraft motion removal algorithm; 2) to obtain a standard set of "ground truth" data for the evaluation of the range tracking capability of high resolution radar altimeters such as the U.S. Navy GEOSAT and other radar systems under development. This report documents the findings of several field tests.

The laser profiler was an Associated Controls and Communications, Inc. (ACCI) PRAM IV. The ACCI PRAM IV is a pulsed diode gallium arsenide laser operating at 904 nanometers (infra-red). The unit transmits a 10 nanosecond pulse at 90 watts of power. It can transmit at a rate of from 1 to 4000 pulses/sec. The laser data is output through a parallel port to the IBM-PC; an RS-232 port is used to communicate with the laser (Figure 1). The control console displays the percent of the transmitted pulses returned to indicate the quality of reception and gives a digital display of the target distance.

## II. Test Sites

### A. Stadium at VPI&SU

On 21 December 1987, flights with the laser system (Figure 2) were made over the football stadium at VPI&SU in Blacksburg, Virginia. The aircraft flew over the stadium at an altitude of ~750 ft. at a speed of 200 kts (approximately 100 m/s). The laser was configured to a 4000 pulse/sec transmission rate. Visual observations were made using the video camera which was looking directly down from the fairing of the aircraft, and also with a 35 mm camera from the cockpit of the aircraft (Figure 3).

Three passes were made over the stadium from a west to east direction. A schematic diagram showing the seating arrangement in the stadium is shown in Figure 4. The laser profile of the first pass over the stadium is shown in Figure 5. As the aircraft approached the stadium, the front vertical wall of the stadium was profiled followed by the descending seats/steps. The aircraft then crossed over the playing field at about the 50 yard line, and the slope of the field, high in the center and lower at the sidelines, is readily discernible. The slope of the field from west to east was due to vertical aircraft motion as the aircraft crossed the stadium. As the aircraft passed over the seats/steps on the eastern side of the stadium, it crossed over one of the portals, an expanded view of which is shown in Figure 6. The dimensions of the seats/steps in the stadium were measured for comparison with the laser data (Figure 7). The vertical distance between the seat tops and the concrete step (approximately 5 inches) was about equal to the vertical resolution of the laser profiler. Also, the horizontal distance between seat tops (14 inches) and the size of the seat tops (11 1/2 inches) was close to the size of the footprint of the laser at an altitude of 750 ft. (12 inches).

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As a result, it was difficult by eye to match up the laser return of the seats/steps exactly with the actual dimensions (Figure 8). A spectral analysis of the laser return was performed on 1309 points for the western side of the stadium giving a frequency of 145.66 Hz (Figure 9). Based on the measured range to the stadium seats and the speed of the aircraft, the peak frequency corresponds to a distance of 25.9 inches from one seat to the next. The actual distance was 26 inches. A second smaller peak at 162.80 Hz translates to a vertical spacing of 22.94 inches. Referring back to Figure 4, there are some aluminum folding seats just below the press box area whose horizontal spacing is 23 inches. It appears as though the laser was able to detect and differentiate the presence of these seats also. The same analysis was performed on 1682 points on the eastern side of the stadium resulting in a frequency peak of 140.04 Hz which translates into a distance of 26.9 inches from one seat to the next (Figure 10). These differences are probably due to the aircraft flightline varying from one side of the stadium to the other. The frequency analysis showed that the laser did indeed resolve the seats/steps dimensions. The frequency spectrum of the playing field was flat, as expected.

B. Buildings at NASA, Wallops Island, Virginia

On 13 January 1988, a flight was made over the NASA facility at Wallops Island, Virginia. The aircraft flew in a southernly direction parallel to the NASA airport runway at an altitude of 500 ft and a speed of 200 kts, overflying a quonset hut, 5 very uniformly spaced buildings, and an aircraft hangar. These buildings can be seen in the photograph which was taken from the cockpit of the aircraft during the approach over the buildings (Figure 11). The quonset hut, as seen by the laser, is shown in Figure 12. The distortion in the shape of the building in the horizontal direction is due to the contracted scale at which the laser profile of the building was plotted. The semi-circular shape of the building is very apparent. Next, the aircraft passed over the five uniform buildings. As the aircraft crossed over the fourth building, it also crossed over an outside door with a small roof which is visible in the laser return (Figure 12). The laser profiler detected trees between the second and third and after the fifth building. The laser observed the height of the building as 36 ft., which is the exact dimension of the building.

The aircraft then proceeded over an aircraft hangar, starting at a point near the front right corner of the building, traveling diagonally up the slope of the right half of the roof, and exiting before reaching the peak of the roof (Figure 13). The false front and back of the building are also clearly seen in the figure.

C. Florida Terrain Flights

A flight was made over Florida in December 1987 along the trackline shown in Figure 14. The trackline was along a sub-track of the U.S. Navy GEOSAT satellite. The track travels nearly up the middle of the state of Florida. This sub-track is also coincident with a sub-track of the SEASAT satellite which was active for 100 days in 1978.

At the southern end of Florida, the land is very flat (see ground profile in Figure 14), consisting mostly of swamp areas with few trees. At about 26°N, the terrain begins to become a little hilly and more trees are encountered. Between 27°N and 29°N, the elevation rises to about 150 ft, the terrain becomes quite complex.

The aircraft flew along the GEOSAT trackline first from north to south, turned around and flew back along nearly the same trackline (within 1 mile) in a northerly direction. The aircraft flew at an altitude of 750 ft and a speed of 200 kts. A portion of the laser return is shown in Figure 15. When the trees are sparse, the laser occasionally penetrates to the ground as can be seen in the first part of the figure. However, as the trees become more dense, the laser beam is reflected only from the tops of the trees. The video camera helped immensely in interpreting the laser return. The open area at the end of the laser return in Figure 15 is an open field.

Continuing along the trackline, two branches of the Withlacoochee River were crossed. On the second branch, the aircraft crossed directly over a bridge (Route 44) which is distinguishable in the laser profile (Figure 16). The flat areas are the river surface with the bridge in the middle. On this expanded scale, the sides of the bridge and the road surface can readily be seen.

Two lakes, Grassy Lake and Eagle Lake, separated by a hill with trees, are shown in Figure 17. The difference in elevation of the surface of the lakes is noticeable; Eagle Lake is about 1 meter lower than Grassy Lake and is confirmed by U.S. Geological Survey Charts. Many lakes were crossed along this trackline. Another common feature that was mapped by the laser profiler was orange groves. The trees in the orange groves are planted in a very regular pattern of orthogonal rows and columns. The laser return in Figure 18 shows the aircraft crossing 40 rows of orange trees which were about 10 ft high. The laser return also shows the space between the trees along with a slight rise in elevation of the ground of about 5 ft from one end of the grove to the other.

Other features which were readily identifiable from the laser profile included roads and highways, and power lines. U.S. Route 27, a dual lane highway, was crossed diagonally and is shown in Figure 19. Drainage ditches are visible on each side of the highway, the lowered grass median between the road, and the road surfaces themselves, sloping outward away from the median for water runoff. Another interesting feature is the powerlines shown in Figure 20. The height of the lines, as determined from the laser return, was 57.4 ft above ground level, and there was a separation of 32.4 ft. between the power lines; a horizontal spacing of 32 ft as verified by the Florida Power and Light Corporation (Mr. Harry Kimbel, personal communication). Using 200 kts as the speed of the aircraft, the "apparent" width of each power line as determined by the laser return was 26.3 inches. In actuality, the diameter of each power line was 1.76 inches. At the altitude of the aircraft as it passed over the power lines, the footprint of the laser was 7.8 inches. It would be expected that the "apparent" width of the powerline would be about the size of the footprint plus the width of the powerline, which would be 9.56 inches. The size of the laser footprint is determined by the nominal beam divergence of the laser system at the half-power point which was

determined to be 1 milliradian. However, due to the high reflective properties of the metal powerlines, the powerlines were sensed at lower power levels by the laser resulting in the larger "apparent" size.

Part of the industrial area of the city of Auburndale is shown in Figure 21. Several buildings and trees are identifiable. Much more detail can be shown, if desired, by plotting the profile at a larger scale.

The entire laser profile for both the north to south and south to north transits are shown in Figures 22 and 23. Various features are noted along the trackline and identified, such as orange groves, lakes, highways, and cities. The elevation is shown for each segment of the trackline. The vertical scale is 30 meters per inch for the elevation and for the features as defined by the laser.

A comparison between the laser profile over Florida with a GEOSAT profile taken on 23 December 1987 along the same trackline is shown in Figure 24. The GEOSAT profile has been intentionally displaced vertically down by 50 feet in the figure for easier visual inspection. The GEOSAT radar altimeter lost tracking between about 27°N and 28°N and no data are available for GEOSAT in this region. The footprint for the GEOSAT radar altimeter is about 2 km. The GEOSAT data were averaged over 1 second during which time the satellite traveled about 7 km in the along track direction resulting in a spatial average over an area of about 2 X 9 km and a much smoother profile than that obtained from the laser profiling system. The two profiles track each other very closely.

A Global Positioning System (GPS) was used to determine the aircraft's location when there were a sufficient number of satellites in view (a minimum of three) to be able to determine latitude and longitude. At other times, the aircraft's Inertial Navigation System (INS) was used to determine the aircraft's location. During most of the flight over Florida, there were three or more satellites in view allowing for a comparison between the GPS and INS. The positions given by both the GPS and INS were compared with identifiable landmarks on U.S. Geological Survey charts. The INS positions were at times off by more than one-half mile, while the GPS positions appear to be within about 100 ft of the actual location, making the GPS a valuable asset during these survey flights.

## III. Summary

The NRL airborne laser profiler system operating with the Global Positioning System (GPS) for precision navigation and the video recording system for visual observations is a valuable "ground truth" data gathering tool. Quantitative evaluations were made with man-made objects such as seats/steps at a football stadium and buildings. Qualitative evaluations were made with natural terrain such as trees, lakes, land elevations, and power lines. The profiling accuracy of the laser system is consistent with the design specifications of ±10 cm range resolution. The height of the buildings at NASA, Wallops Island as determined by the laser, agreed with the measured height of the buildings to the accuracy attainable with a tape measure. The laser profiler was able to detect power lines as small as 1.76 inches in diameter and the spacing between the power lines

as determined by the laser agreed within about 8 cm of the engineering drawing specifications. Finally, the dimensions of the steps and seats at the football stadium were resolved to within about 2 cm of their actual spacing.

## IV. Acknowledgments

We would like to thank Dr. Gary Brown of VPI&SU for making the measurements of the seats/steps of Lane Stadium, and Drs. George Hayne and Dave Hancock of NASA, Wallops Island for providing information relative to our flights over that facility.

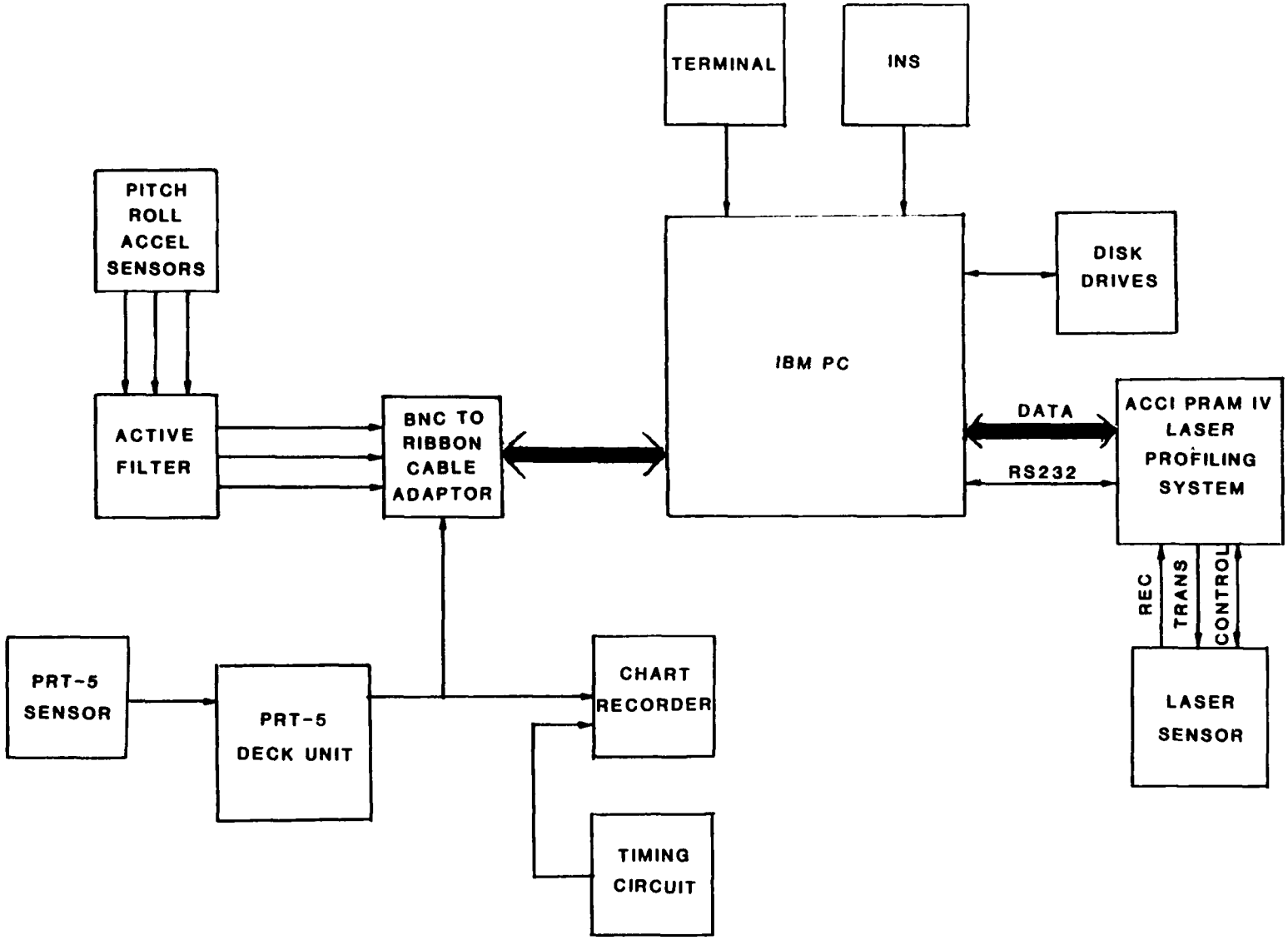


Figure 1. Block diagram of the Laser Profiling System and Data Acquisition System.

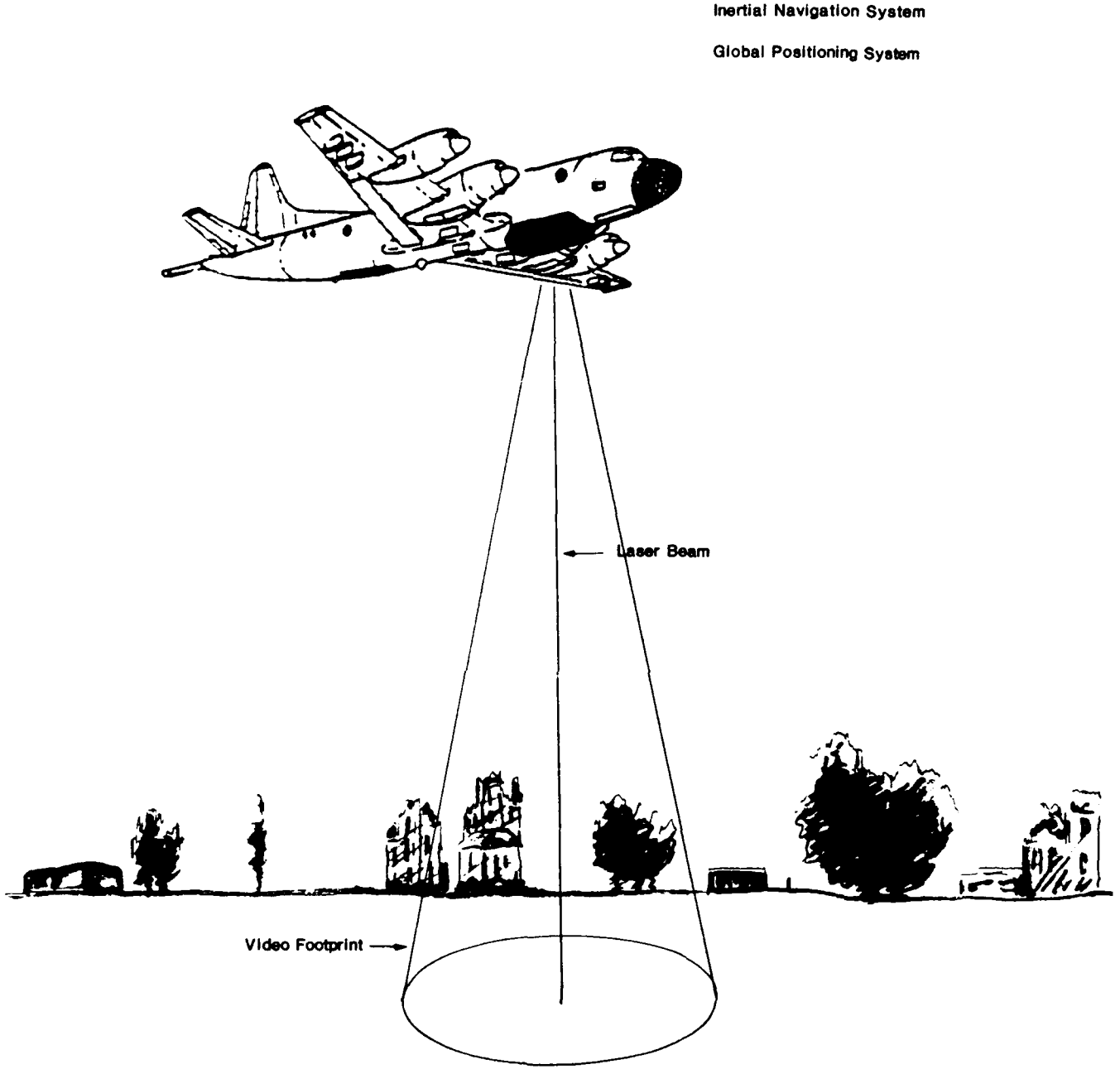


Figure 2. NRL RP-3A aircraft showing location of sensors.

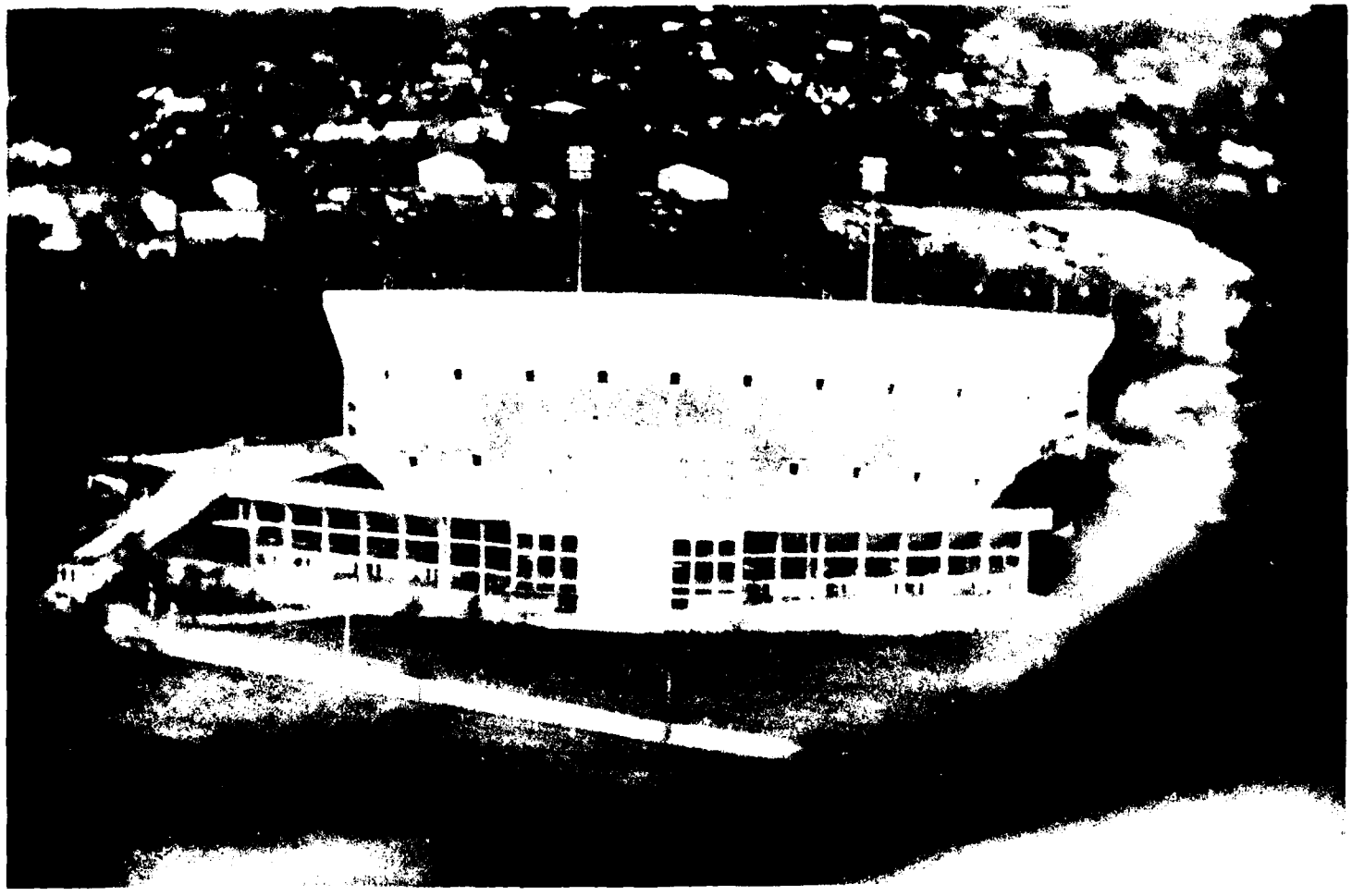

Figure 3. Aerial view of VPI&SU football stadium.

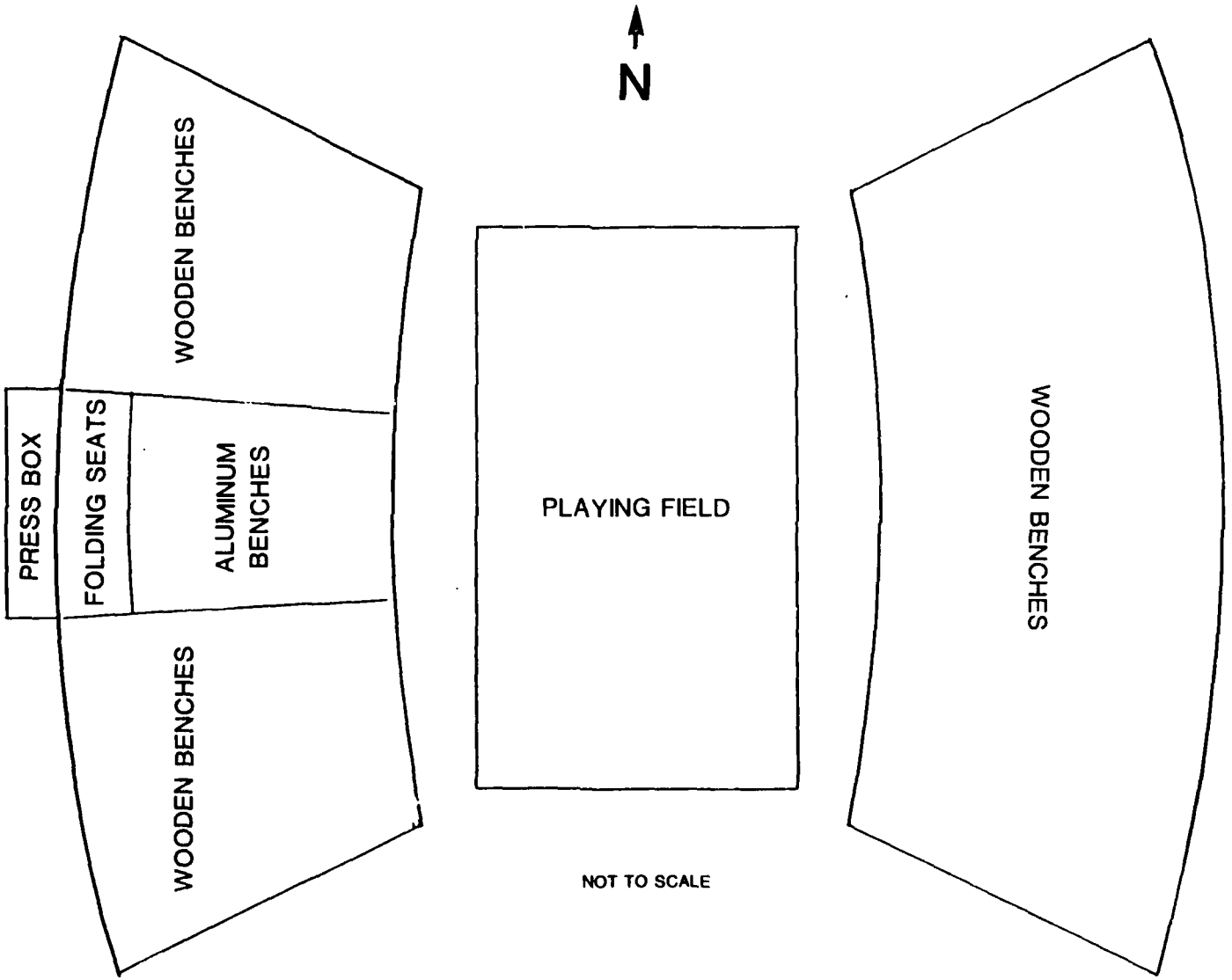


Figure 4. Schematic drawing of VPI&SU football stadium.

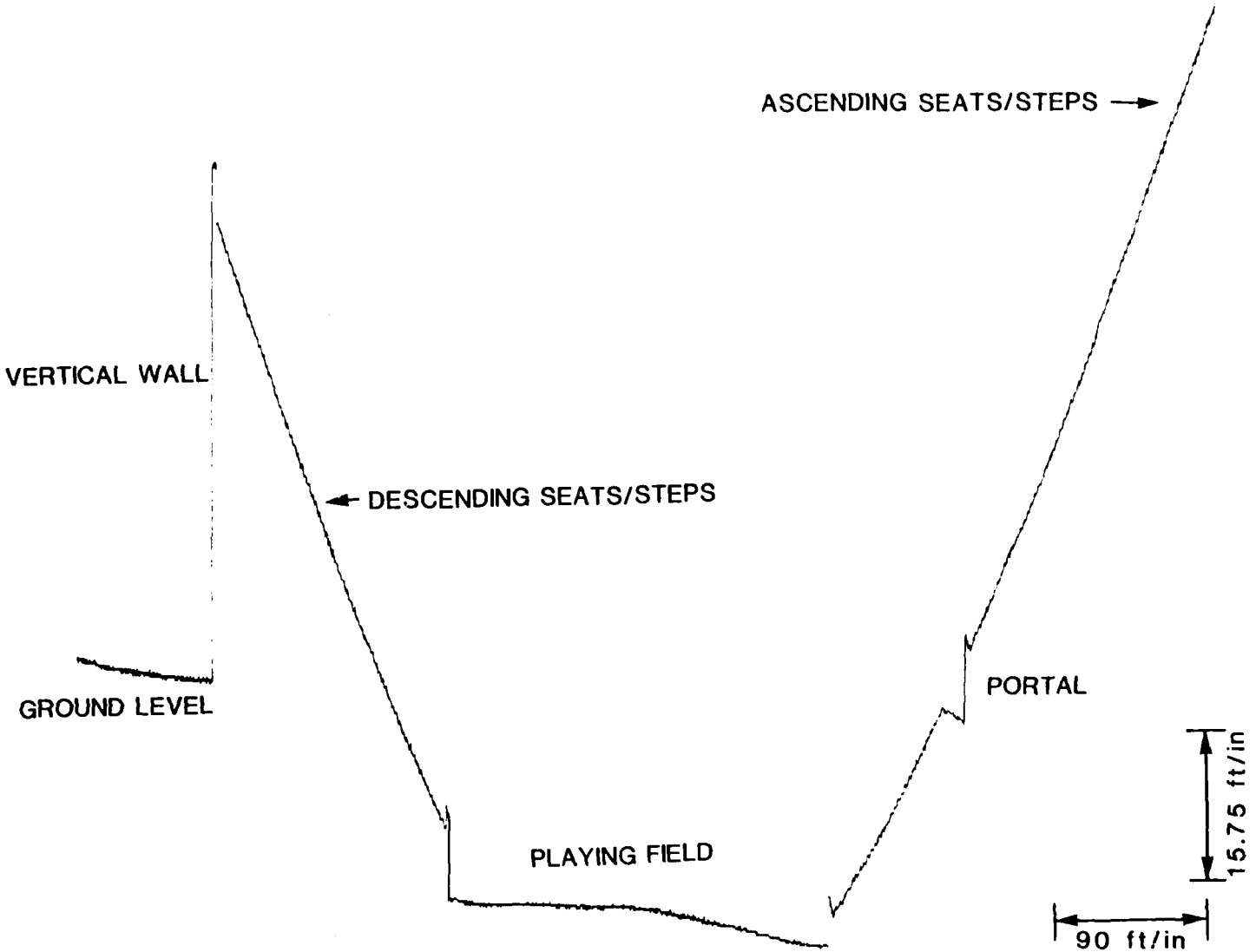


Figure 5. Laser profile of VPI&SU football stadium.

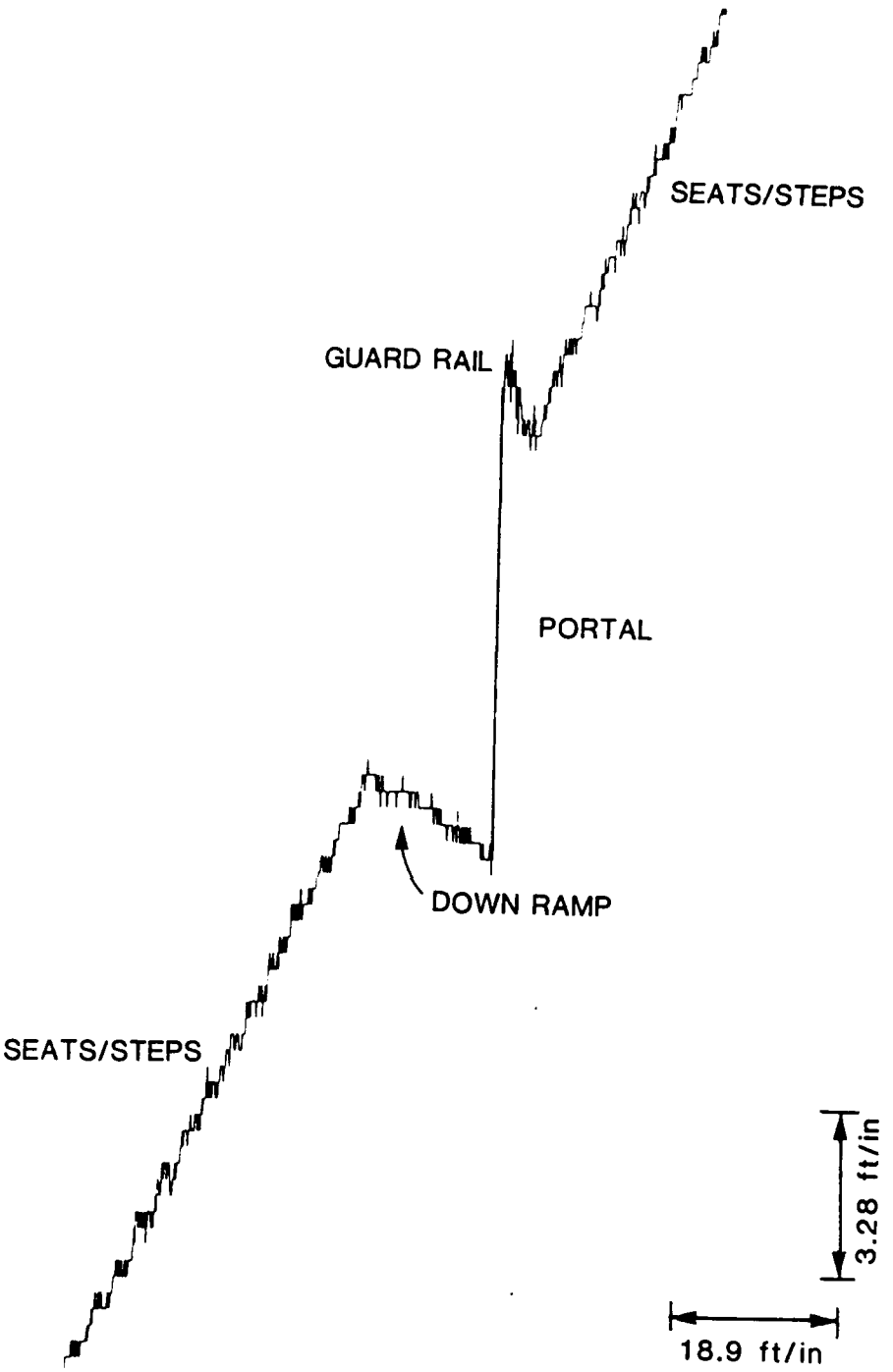


Figure 6. Expanded view of laser profile of portal.

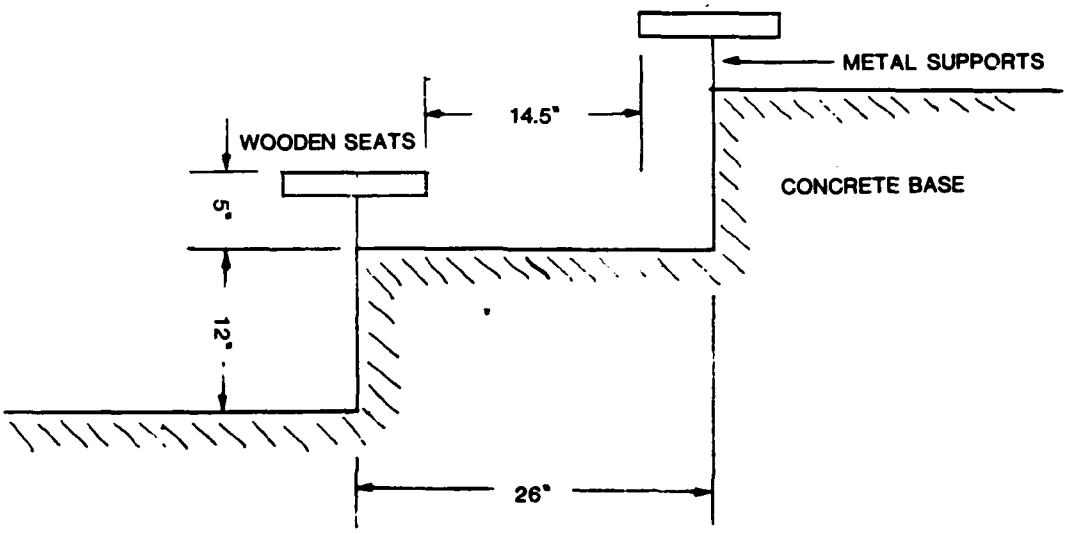


Figure 7. Diagram of seats/steps at VPI&SU football stadium.

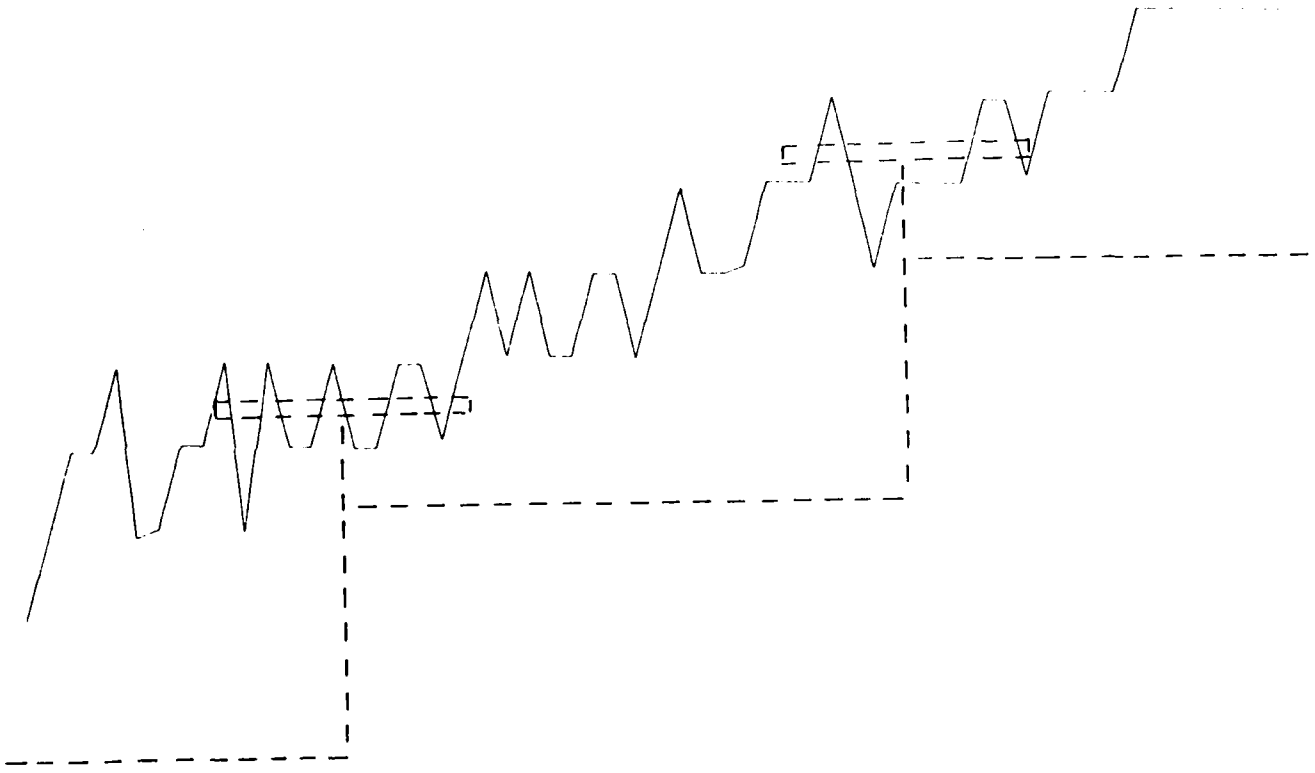

Figure 8. Laser profile and seats/steps comparison.

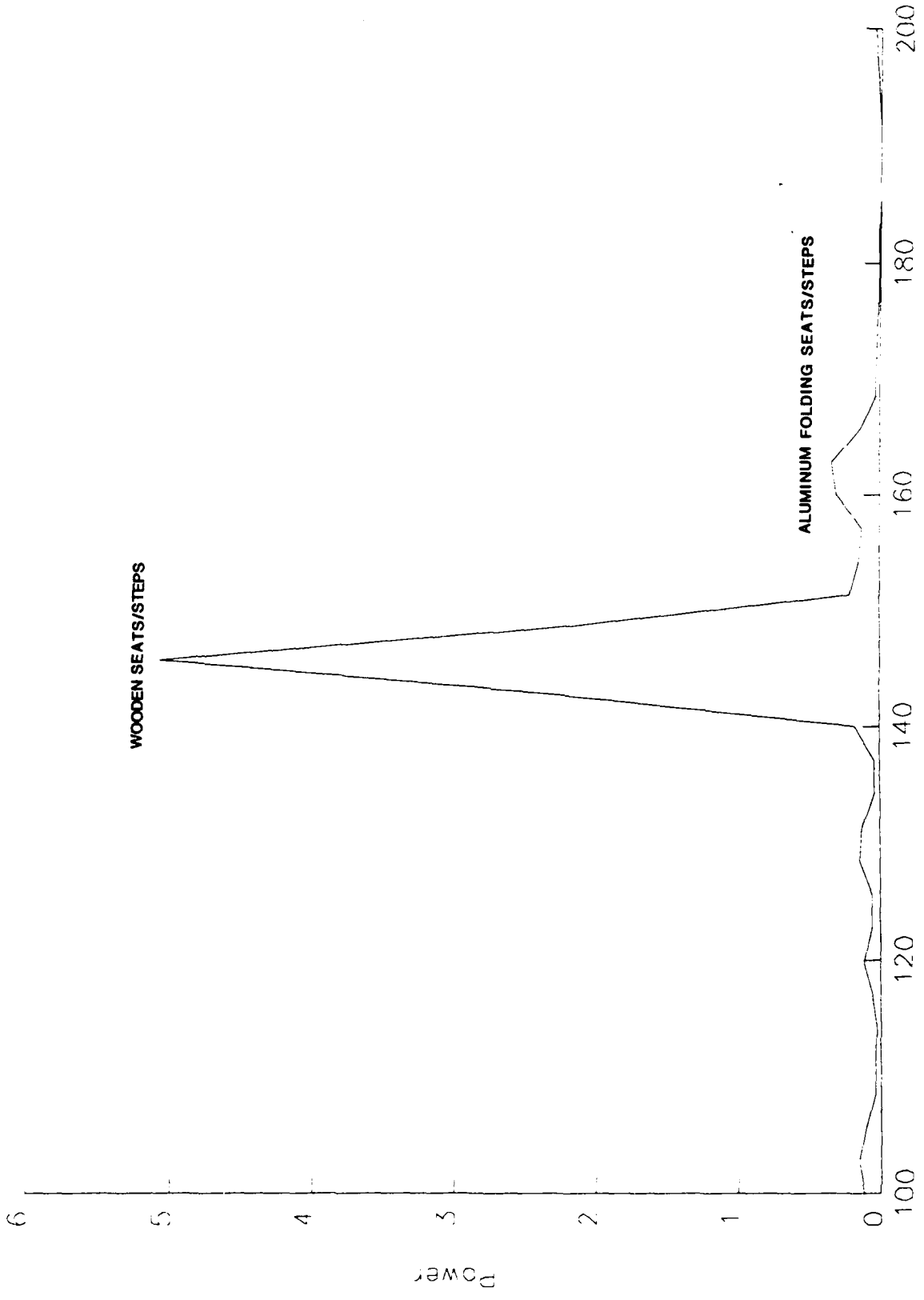


**Figure 9. Frequency spectrum of West seats/steps.**

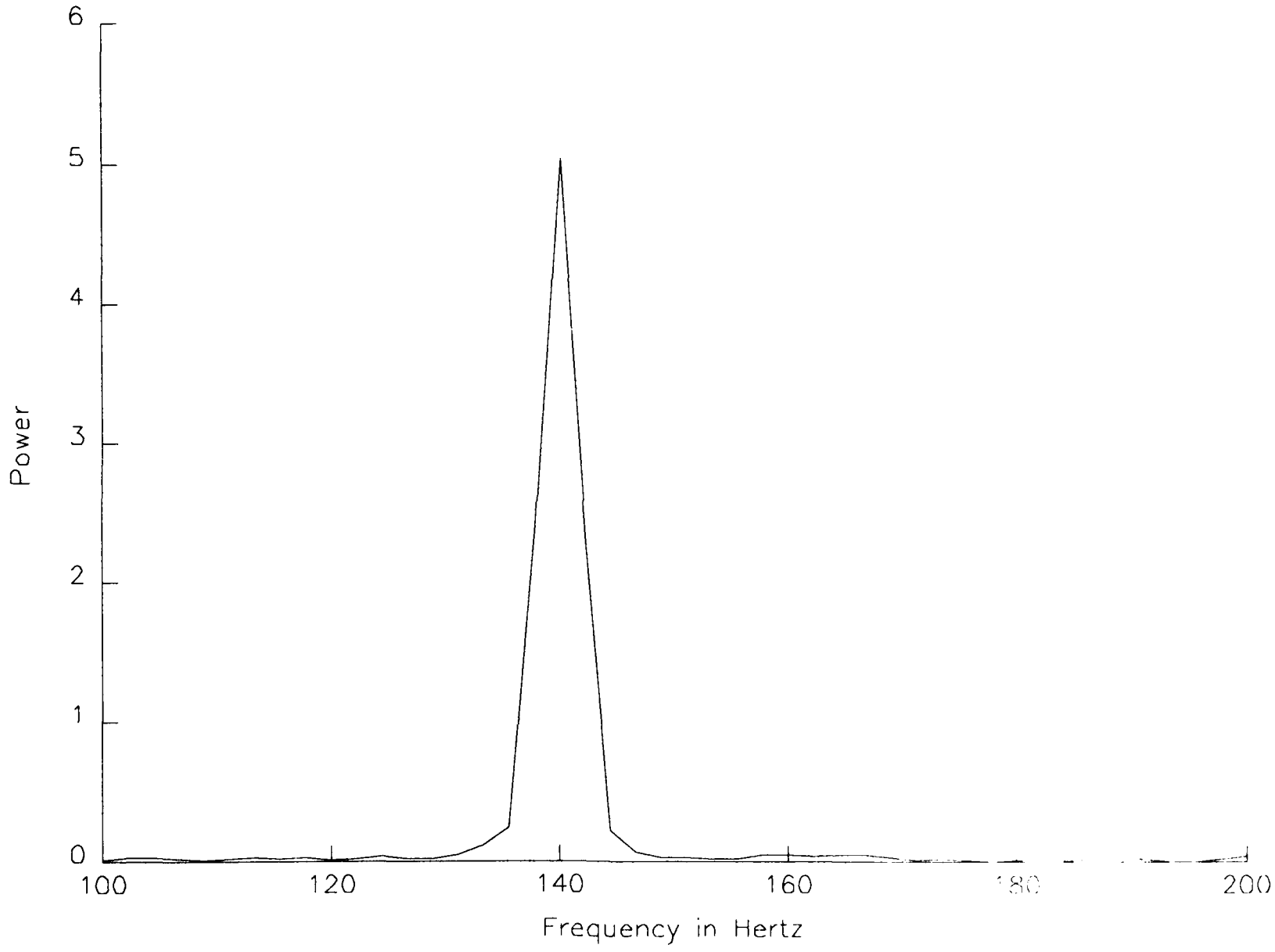


**Figure 10. Frequency spectrum of east seats/steps.**

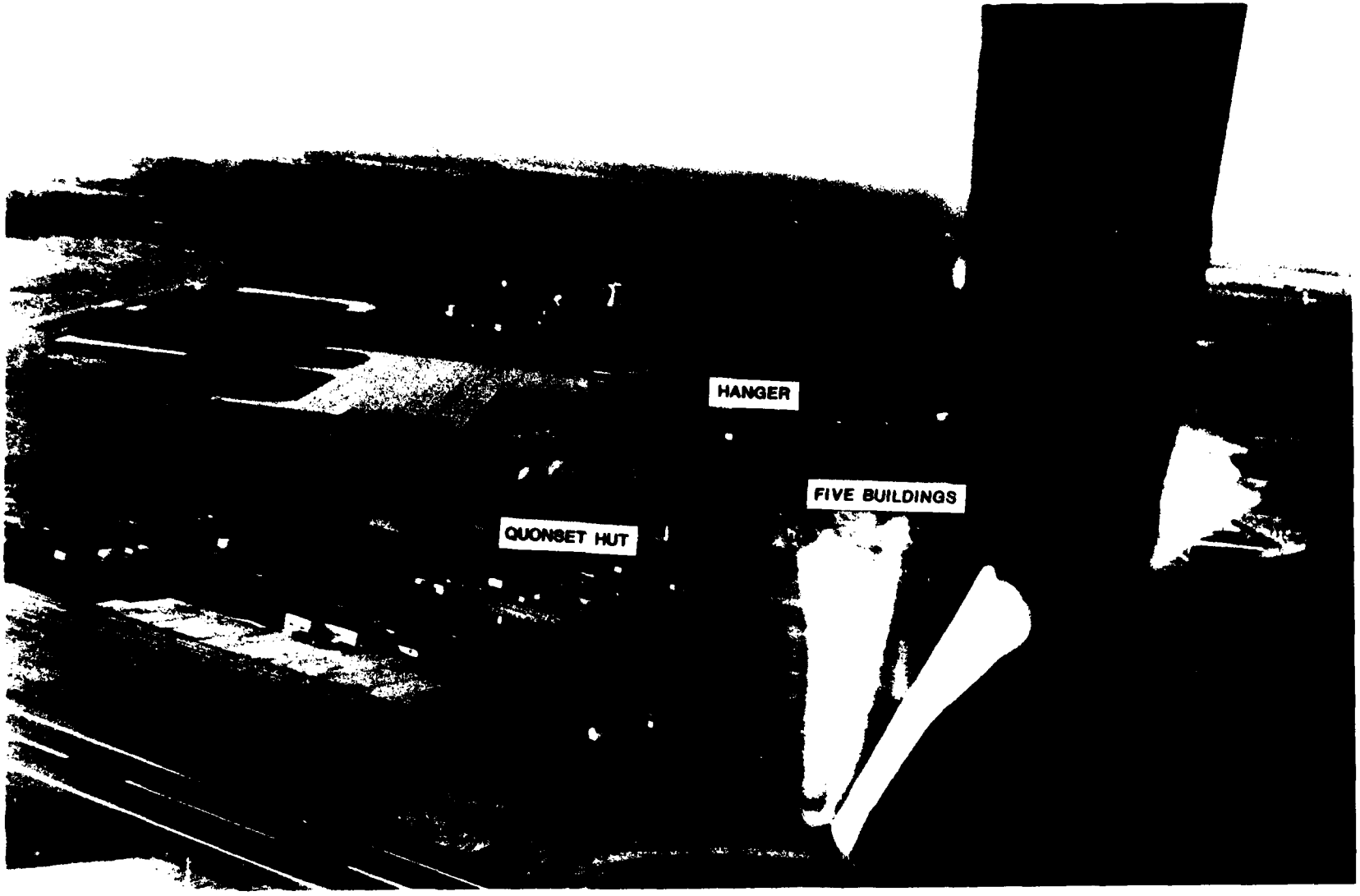


Figure 11. Aerial photo of NASA, Wallops Island, Virginia.

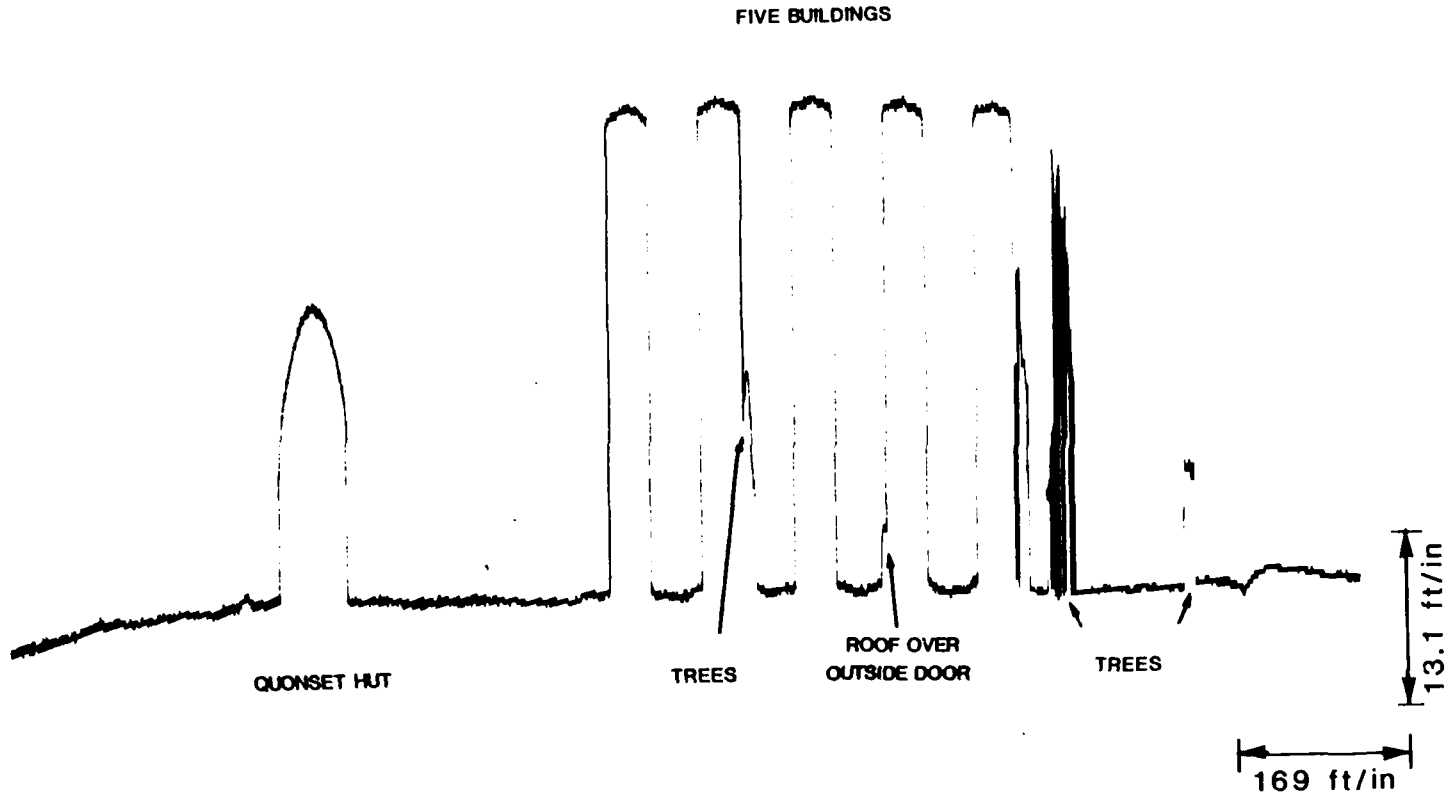


Figure 12. Quonset hut and five buildings at Wallops Island.

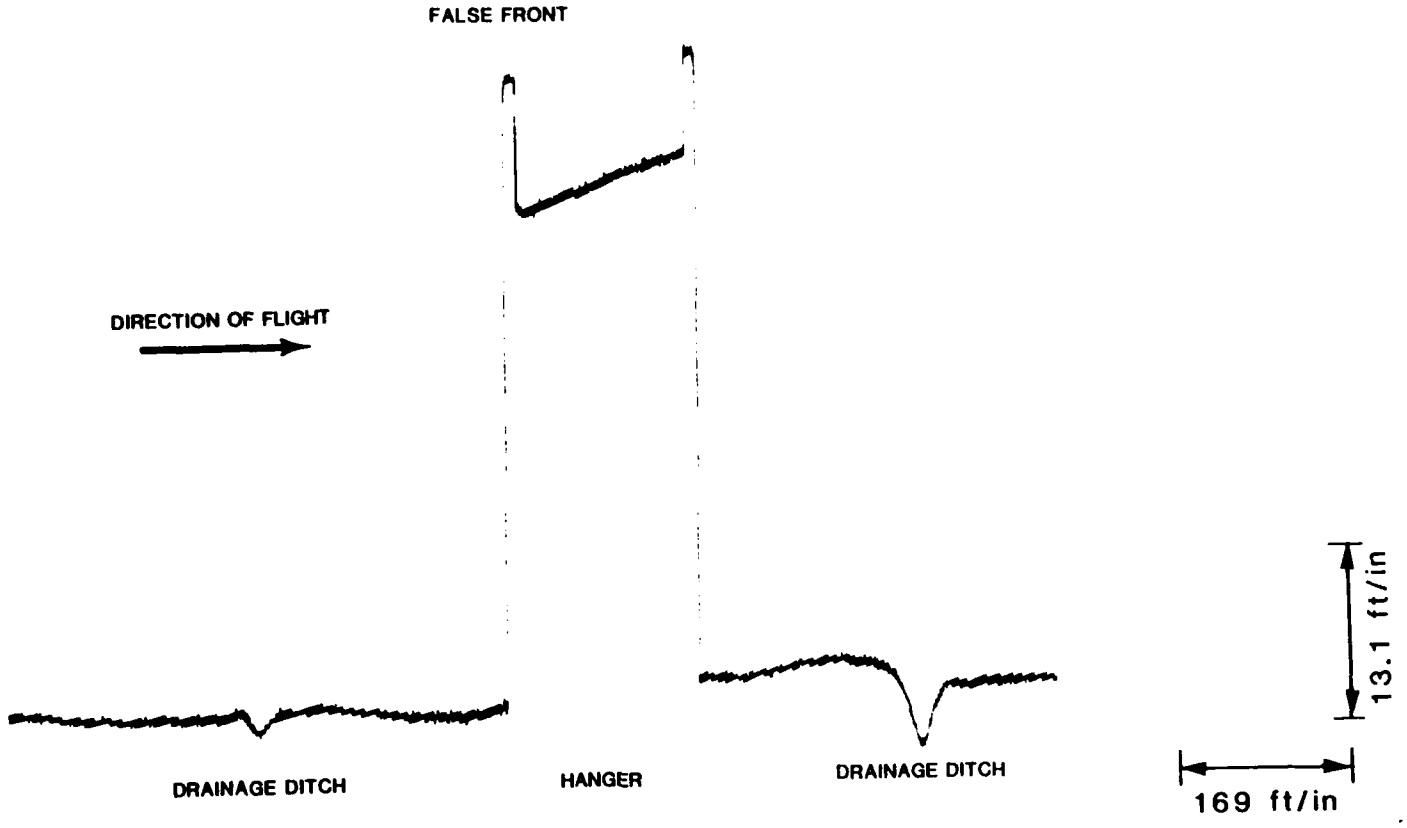


Figure 13. Aircraft hangar at Wallops Island.

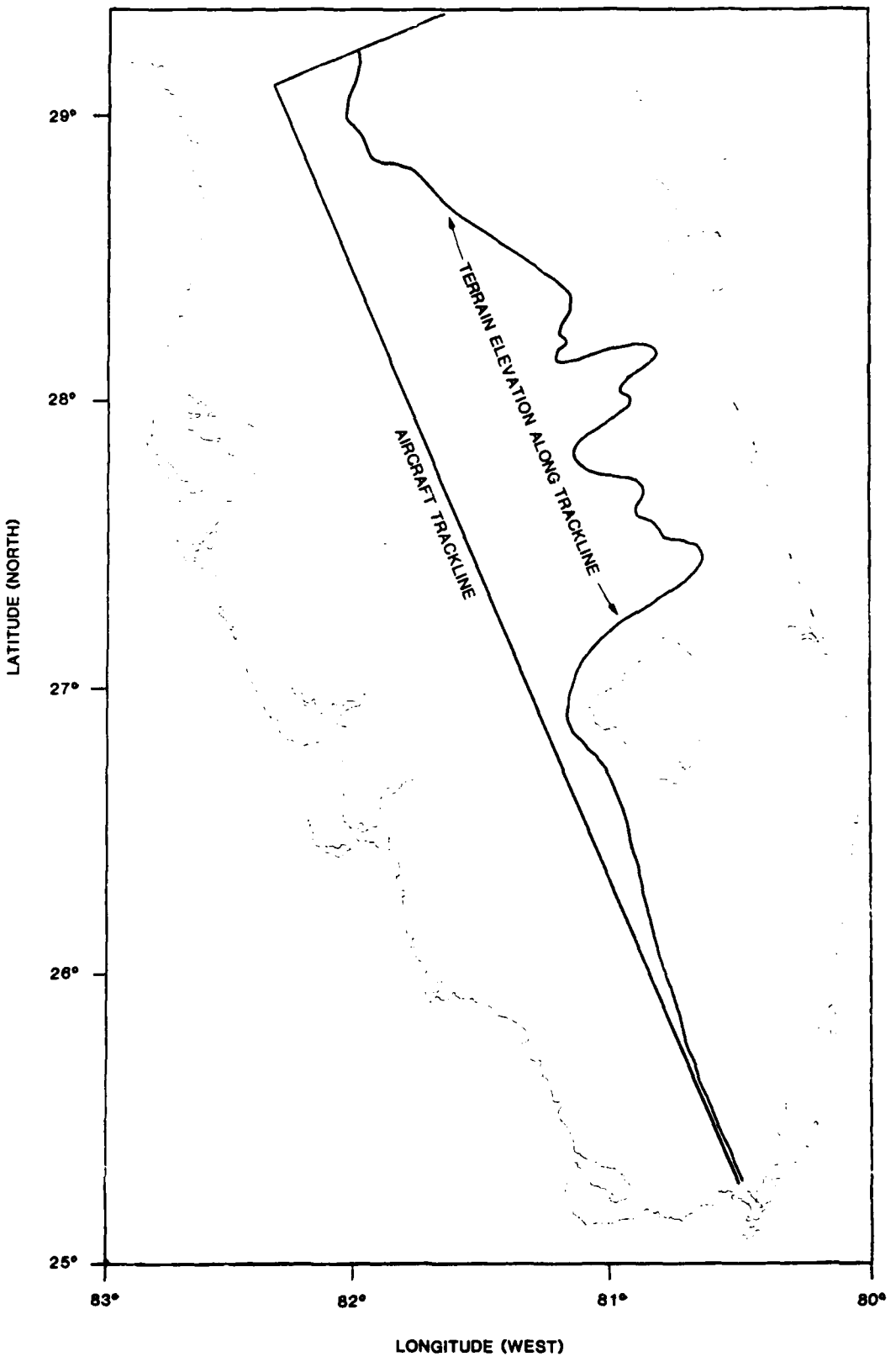


Figure 14. Aircraft trackline over Florida.

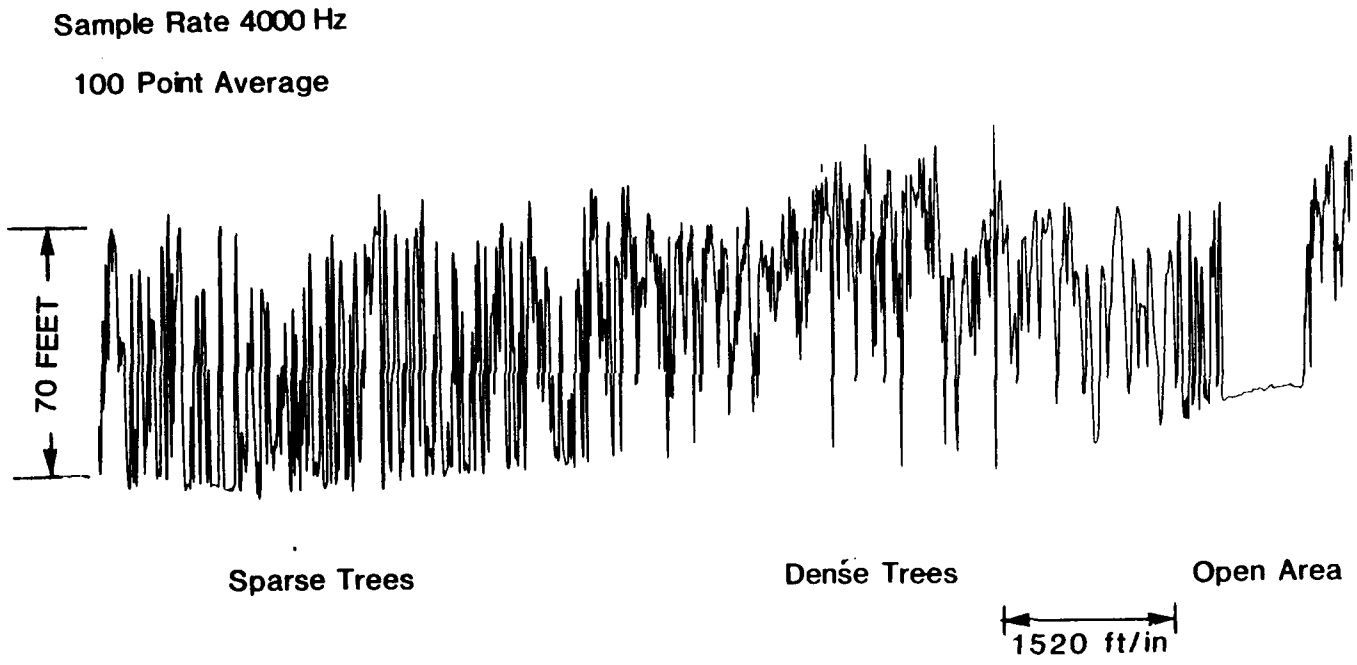


Figure 15. Laser profile of dense/sparse forest.

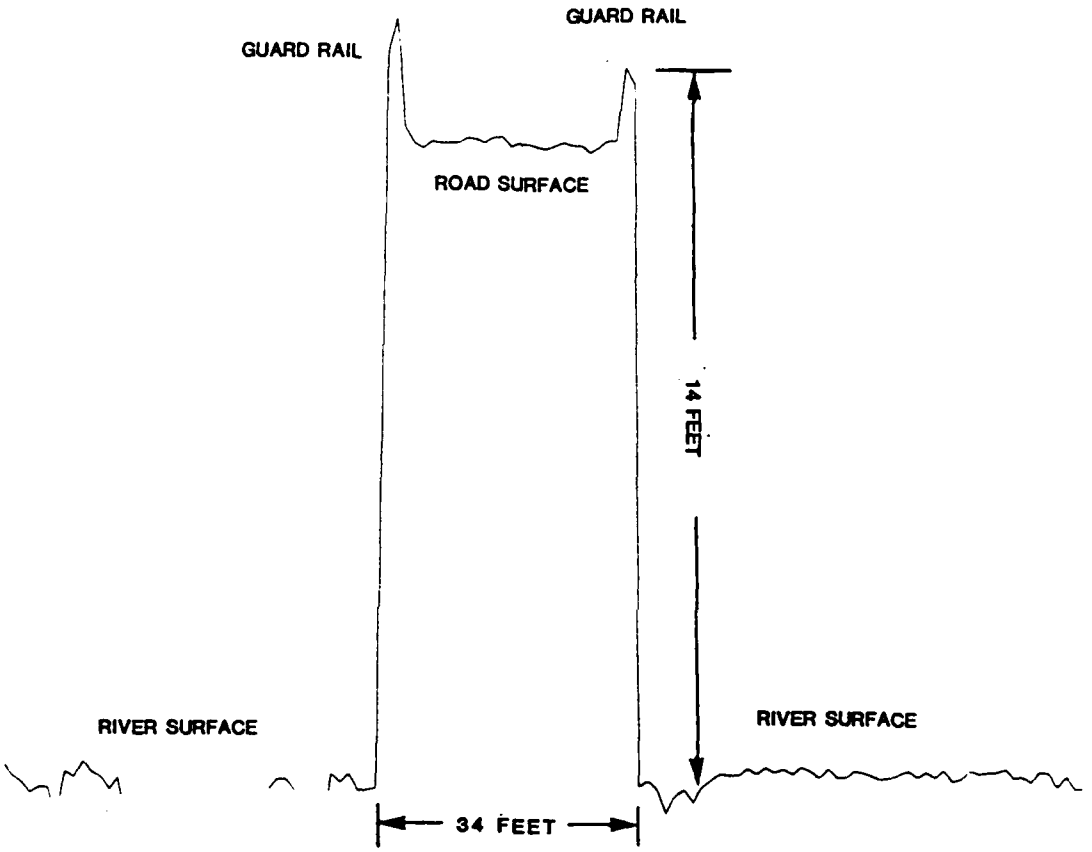


Figure 16. Laser profile of Withlacoochee River and bridge.

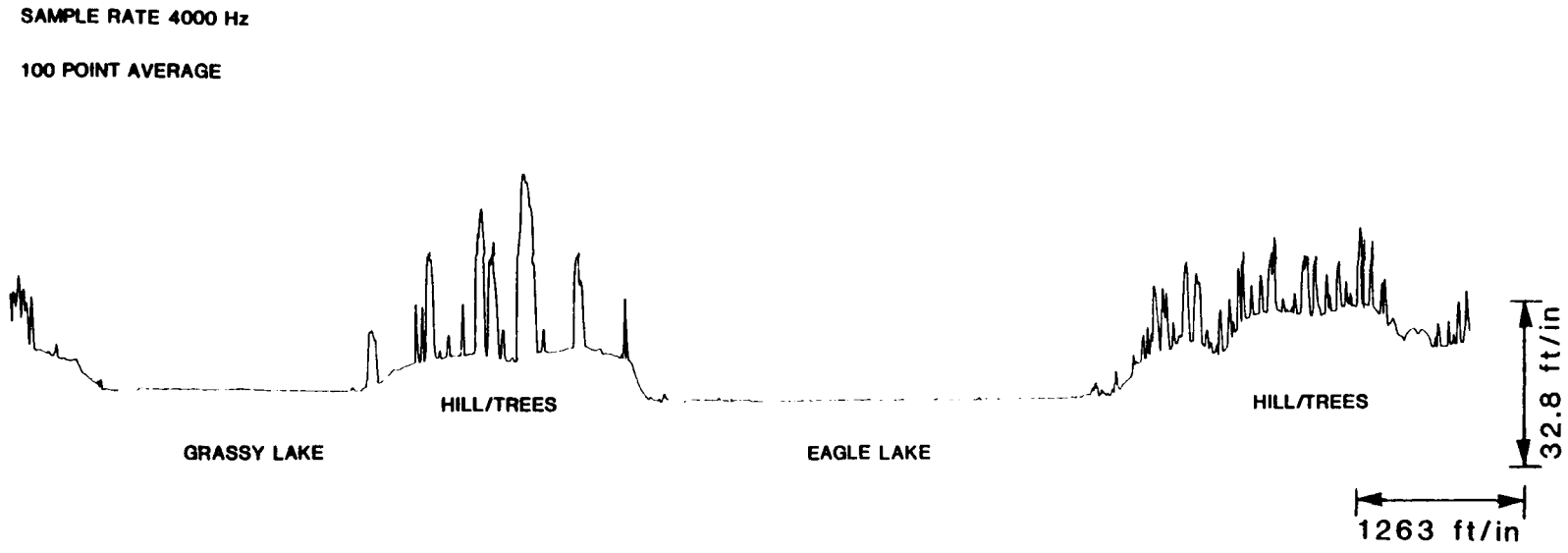


Figure 17. Laser profile of lakes.

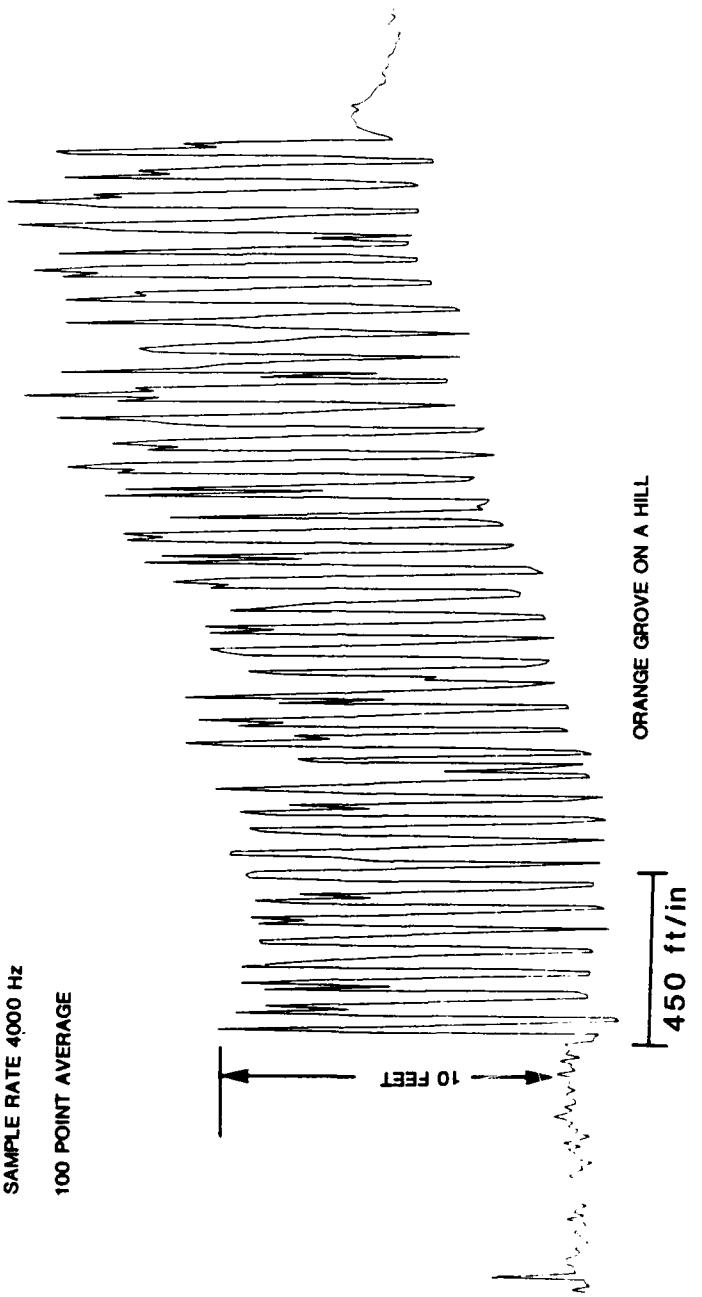


Figure 18. Laser profile of an orange grove.

SAMPLE RATE 4000 Hz

200 POINT AVERAGE

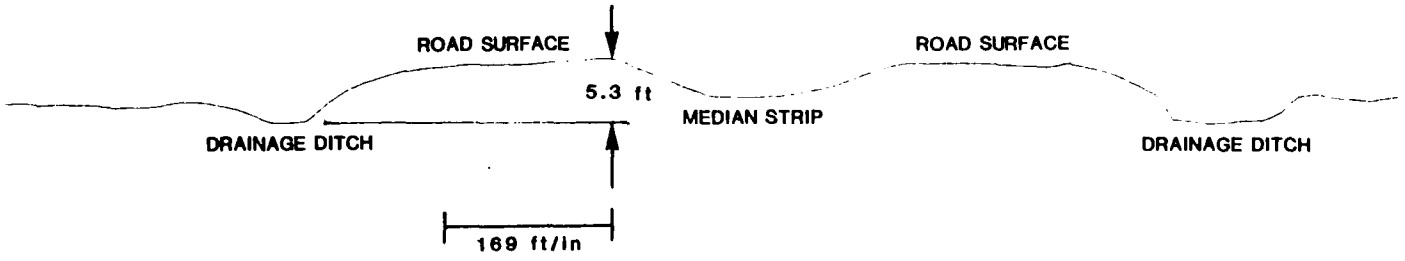


Figure 19. Laser profile of U.S. Route 27.

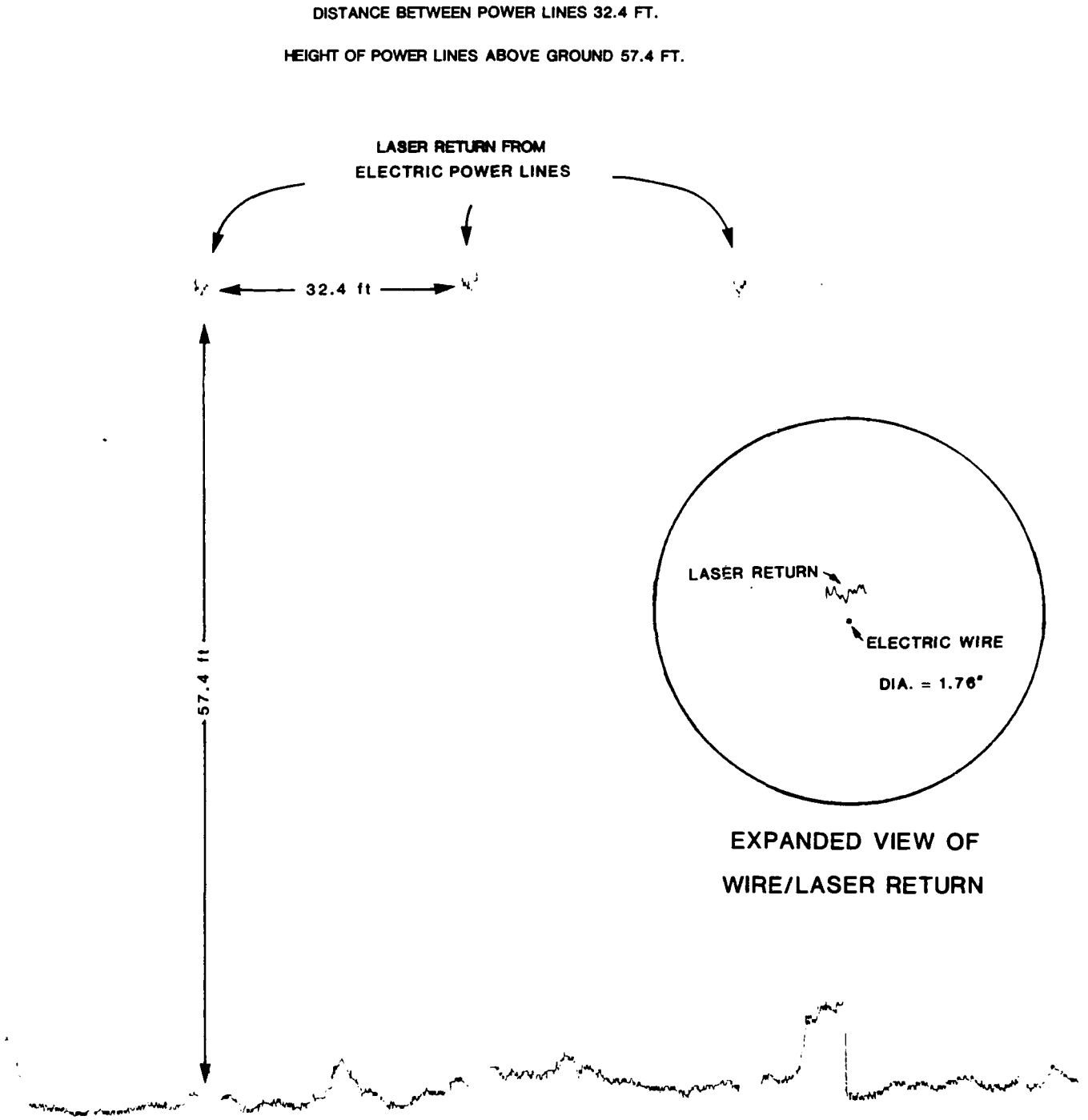


Figure 20. Laser profile of power lines.

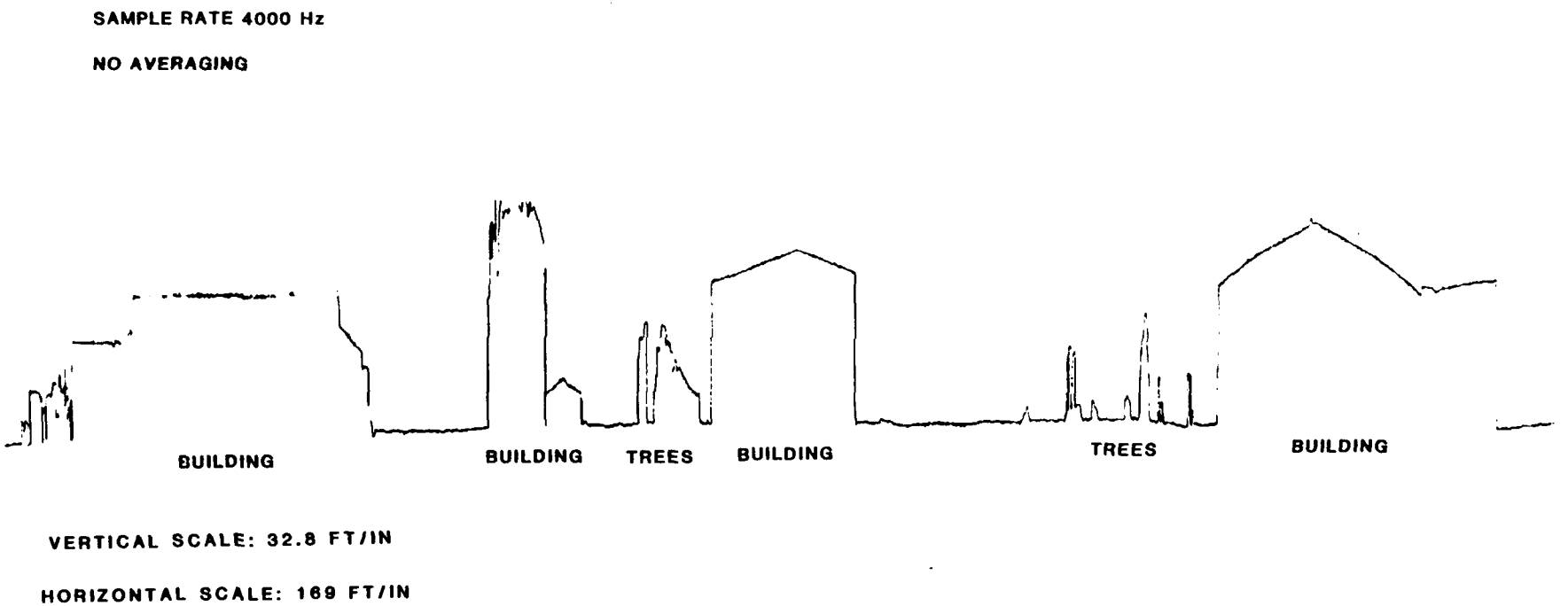


Figure 21. Laser profile of the city of Auburndale industrial area.

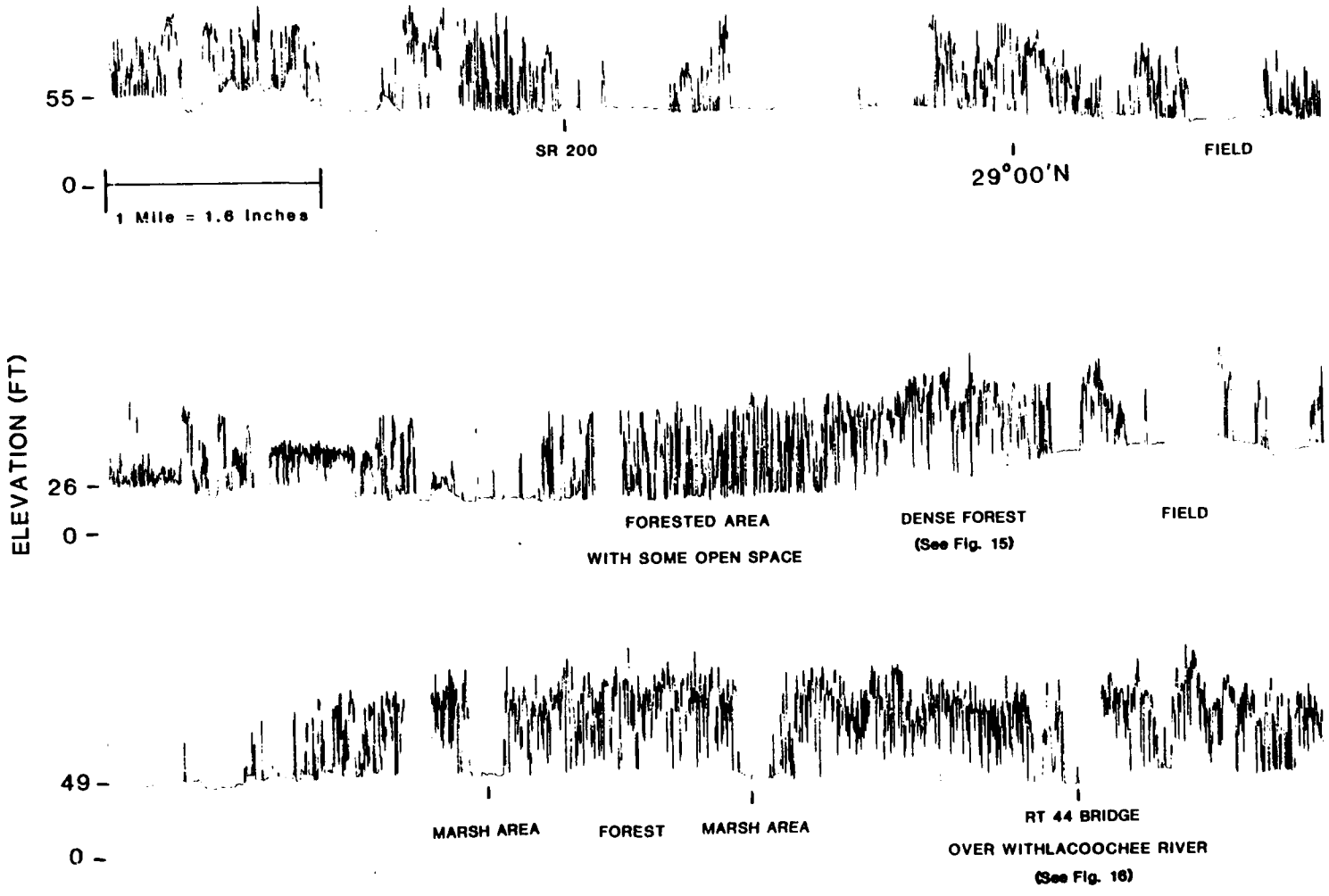


Figure 22. Laser profile along the entire north/south trackline over Florida.

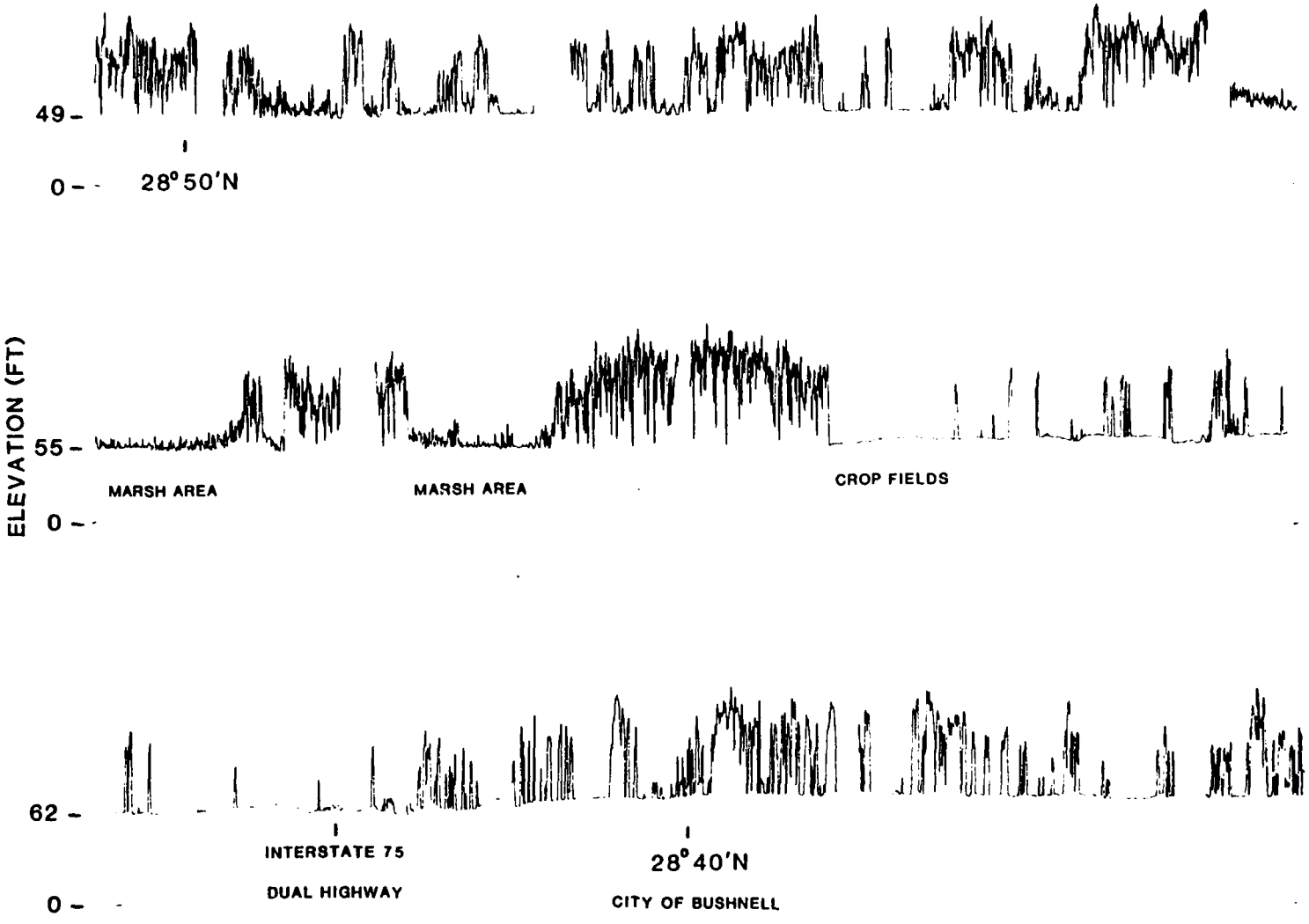


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

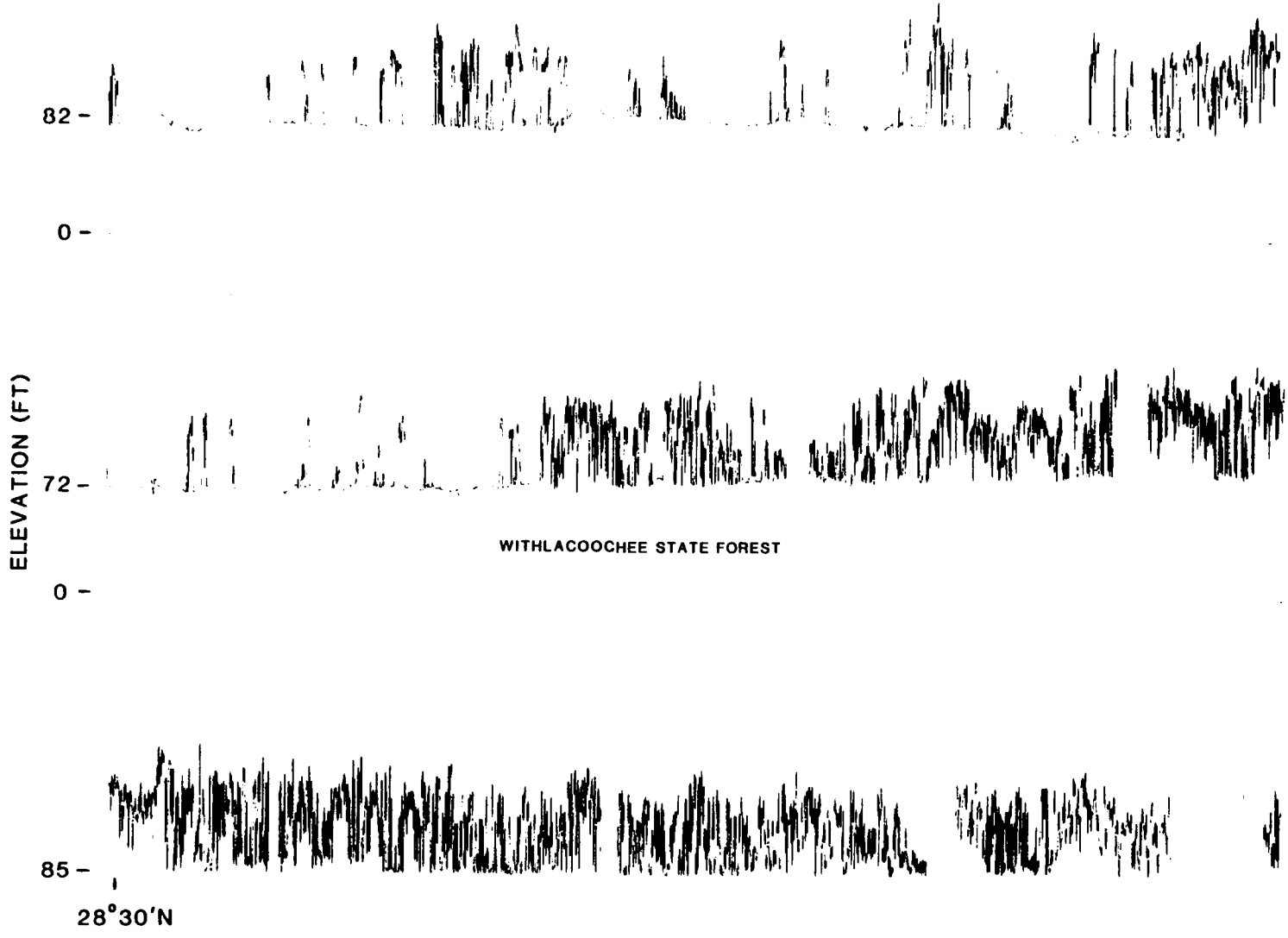


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

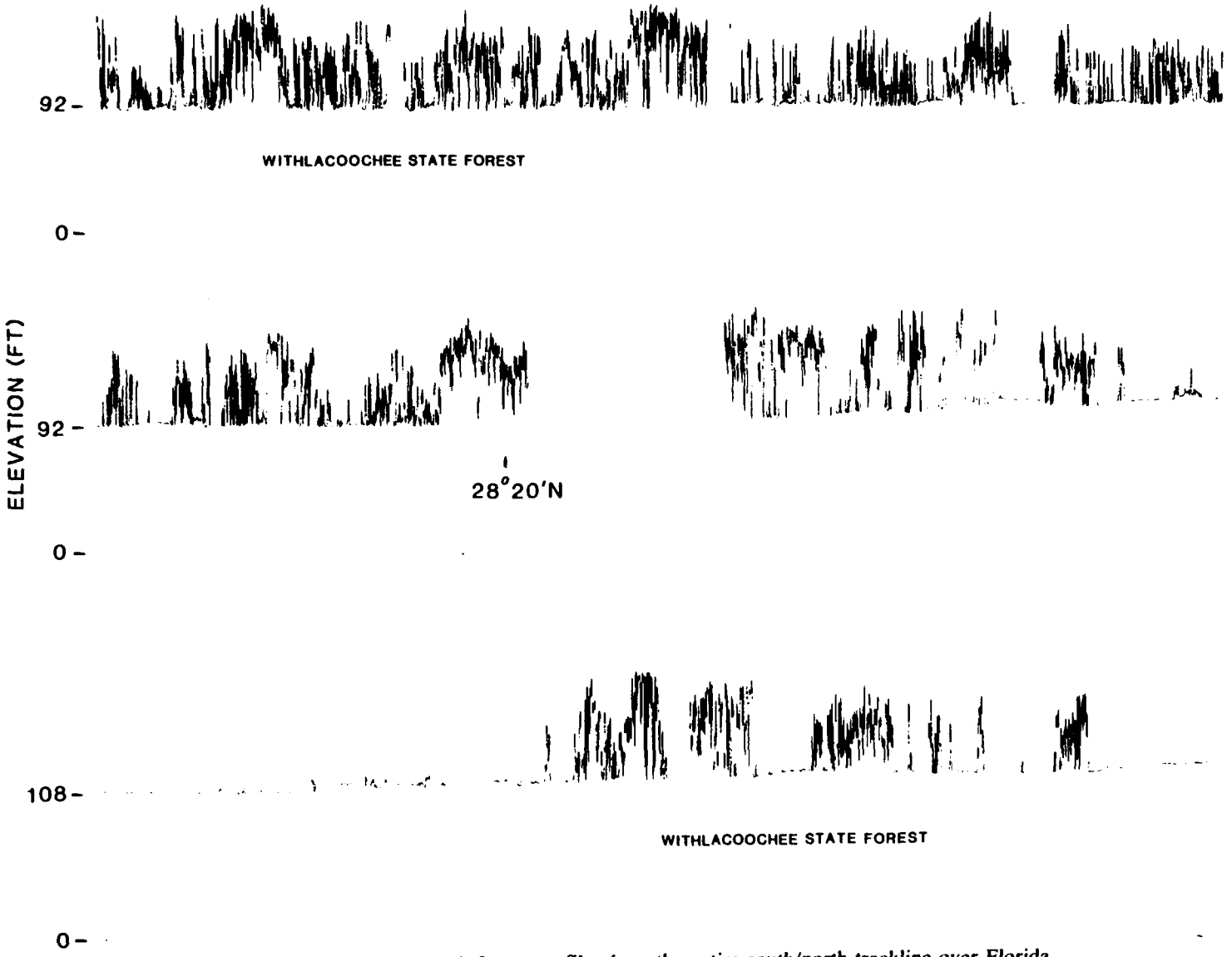


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

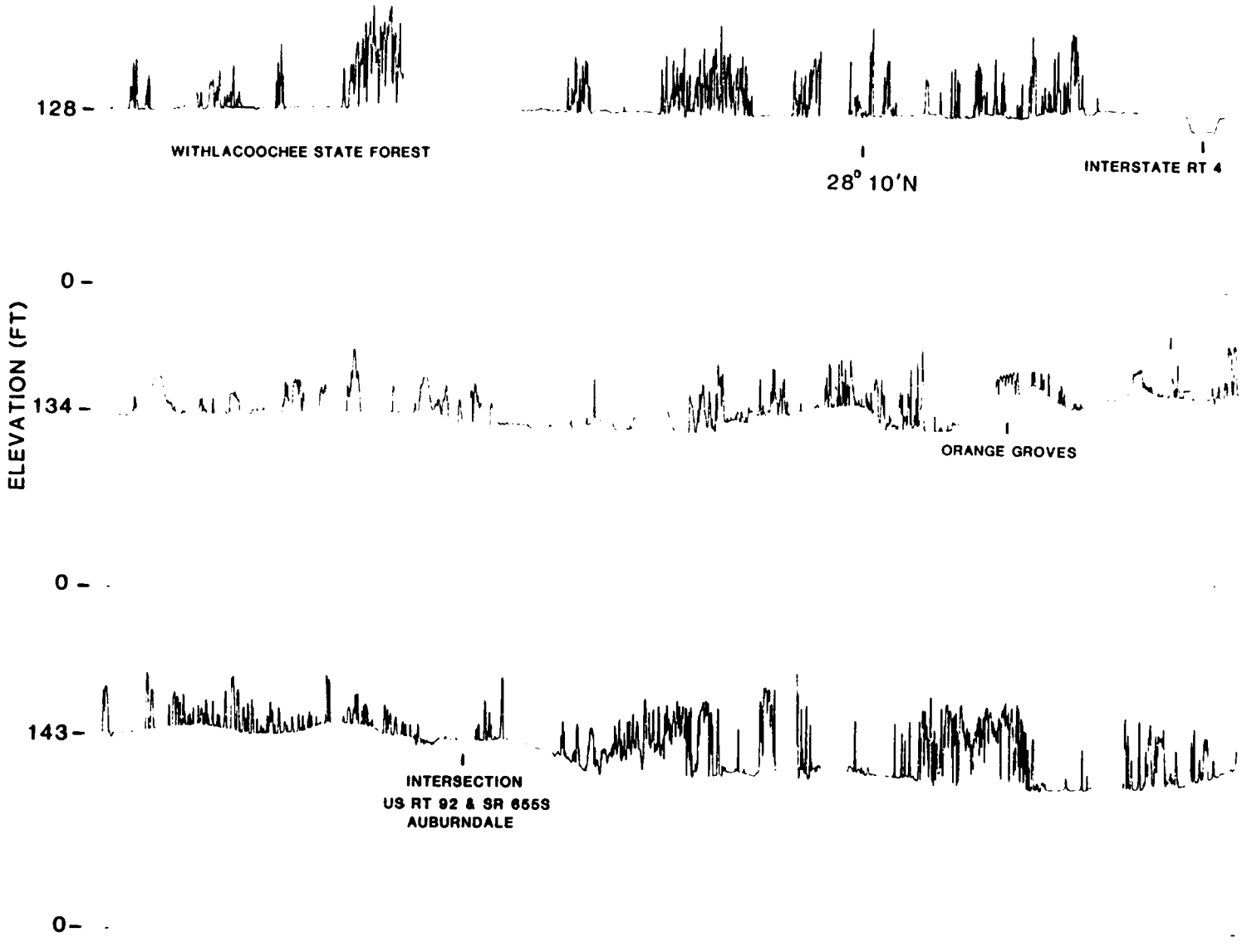


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

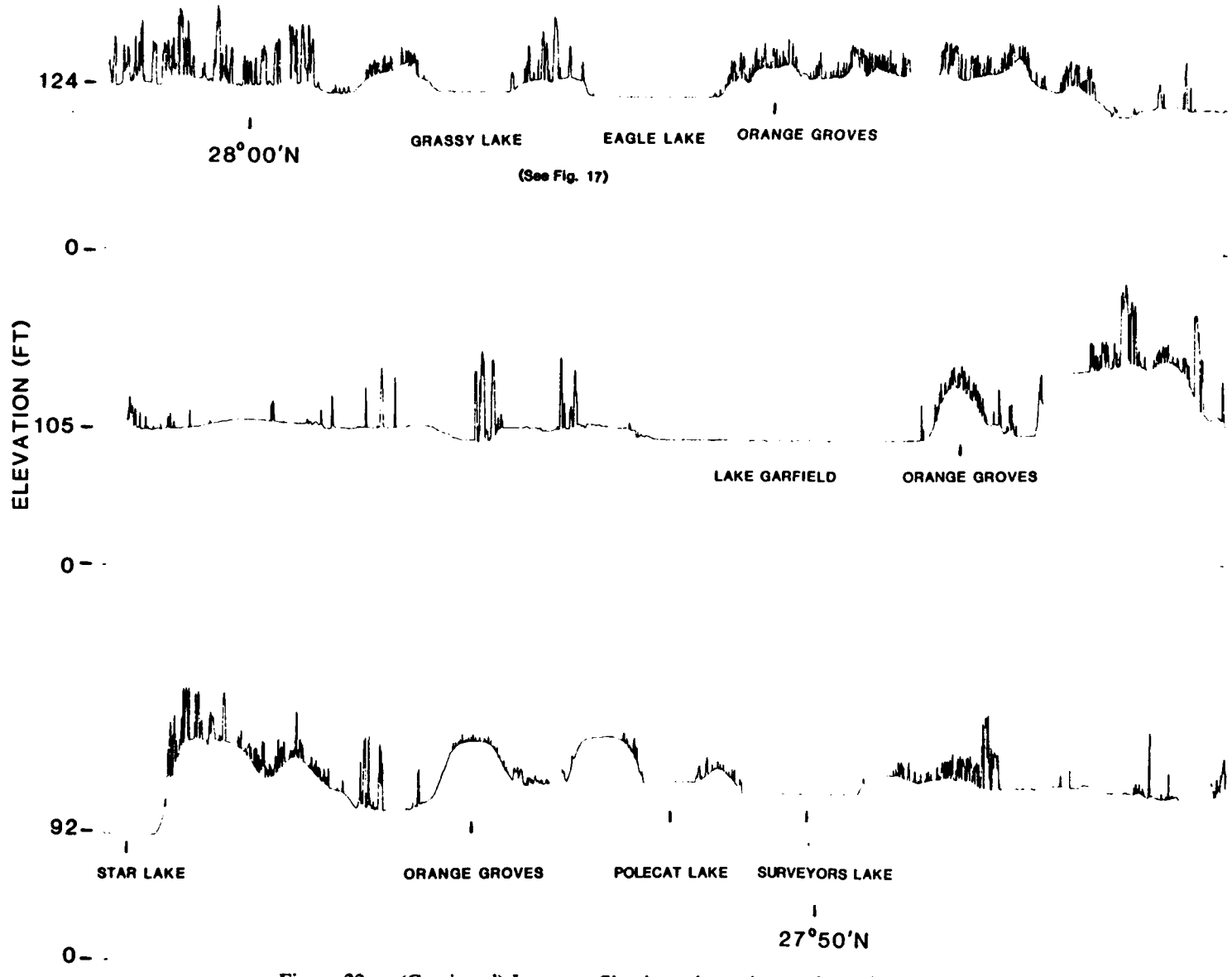


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

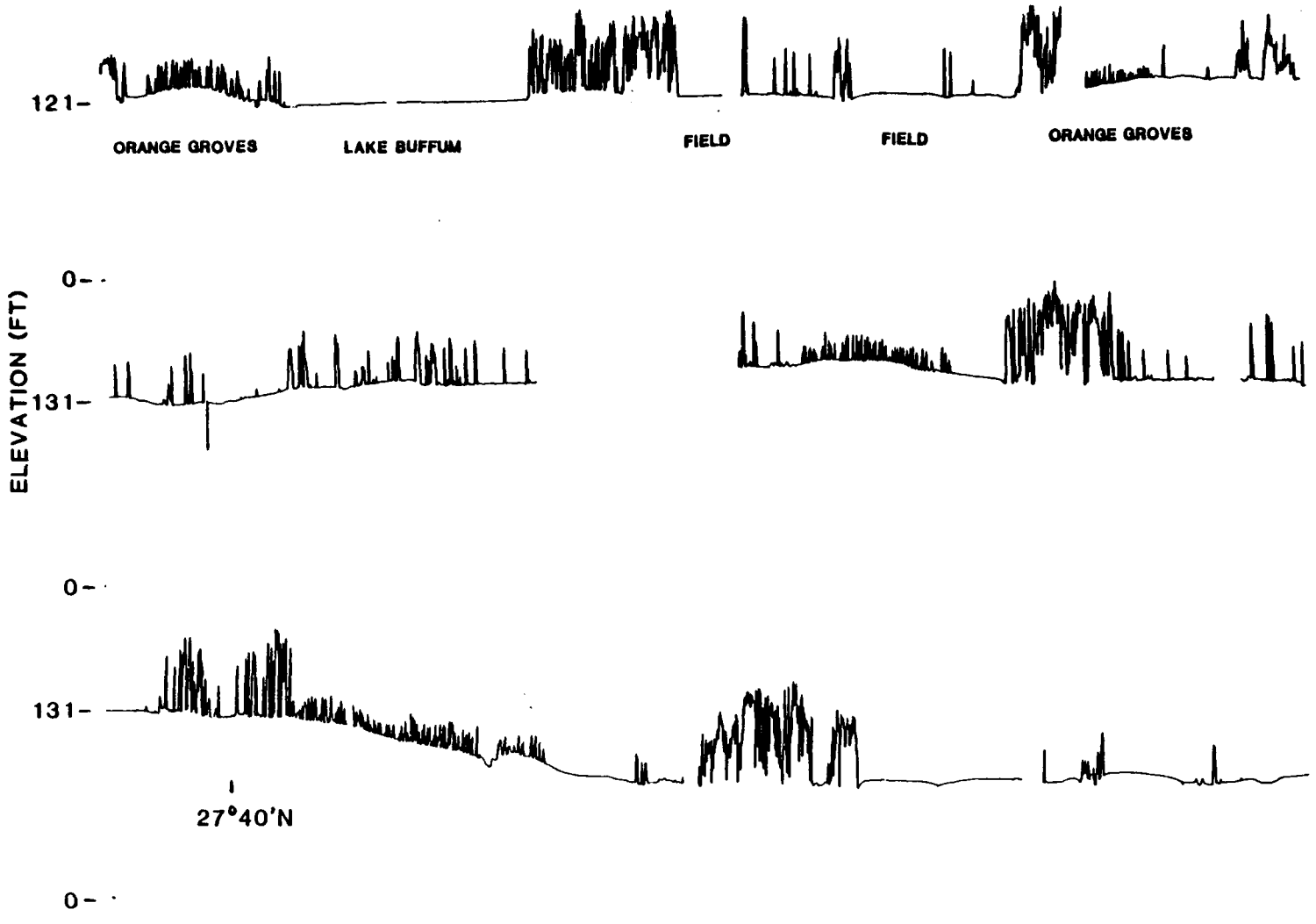


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

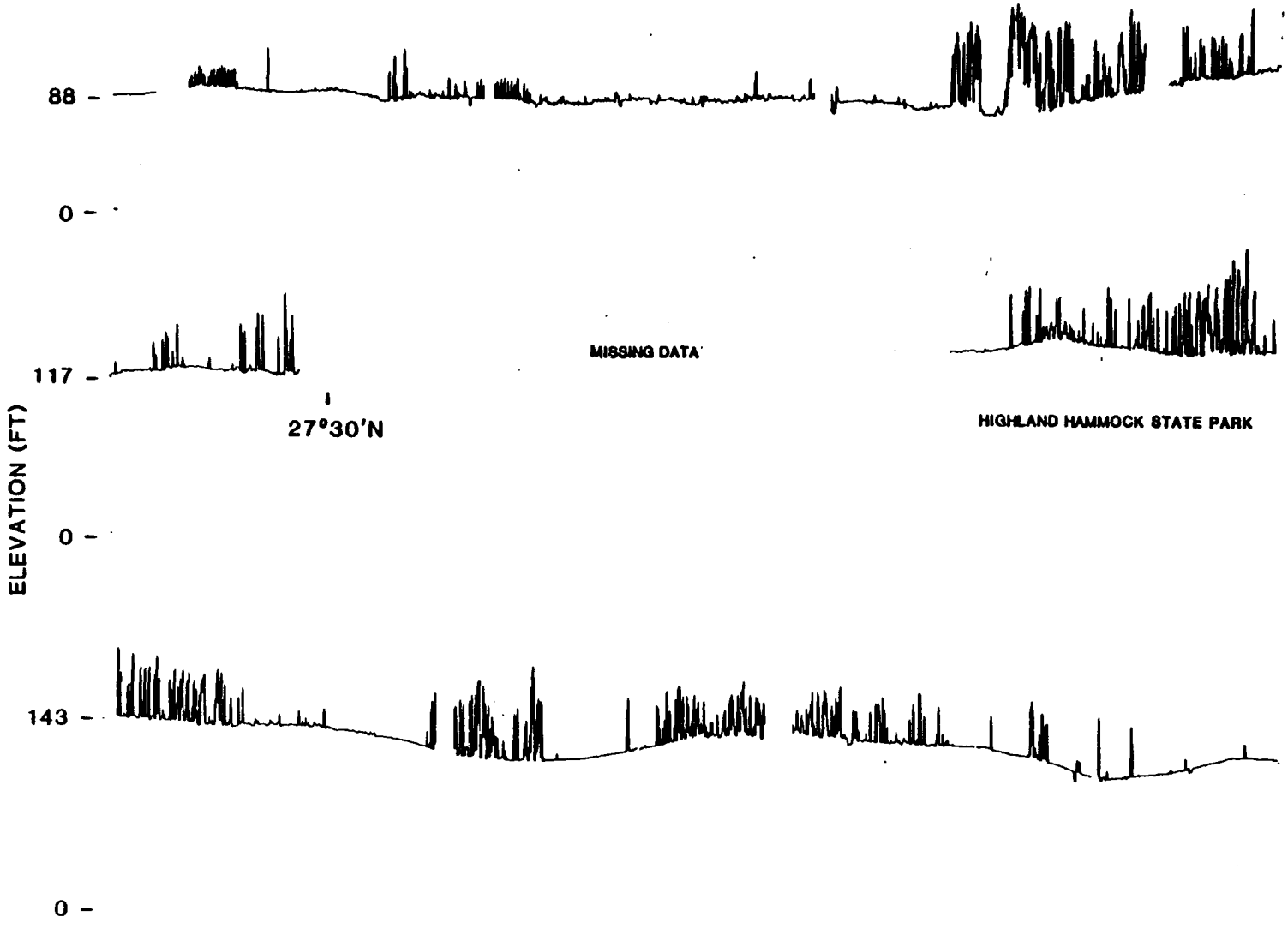


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

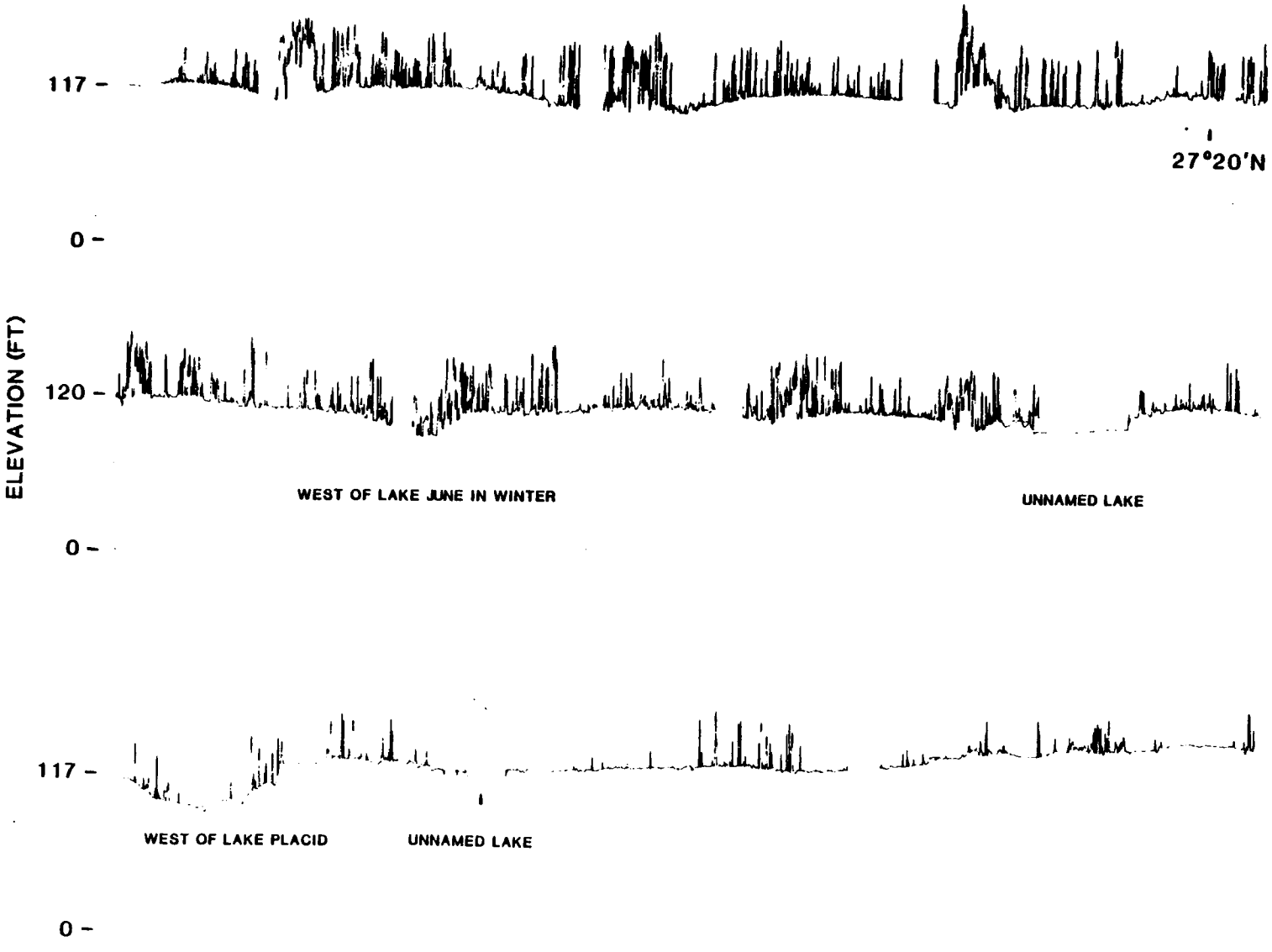


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

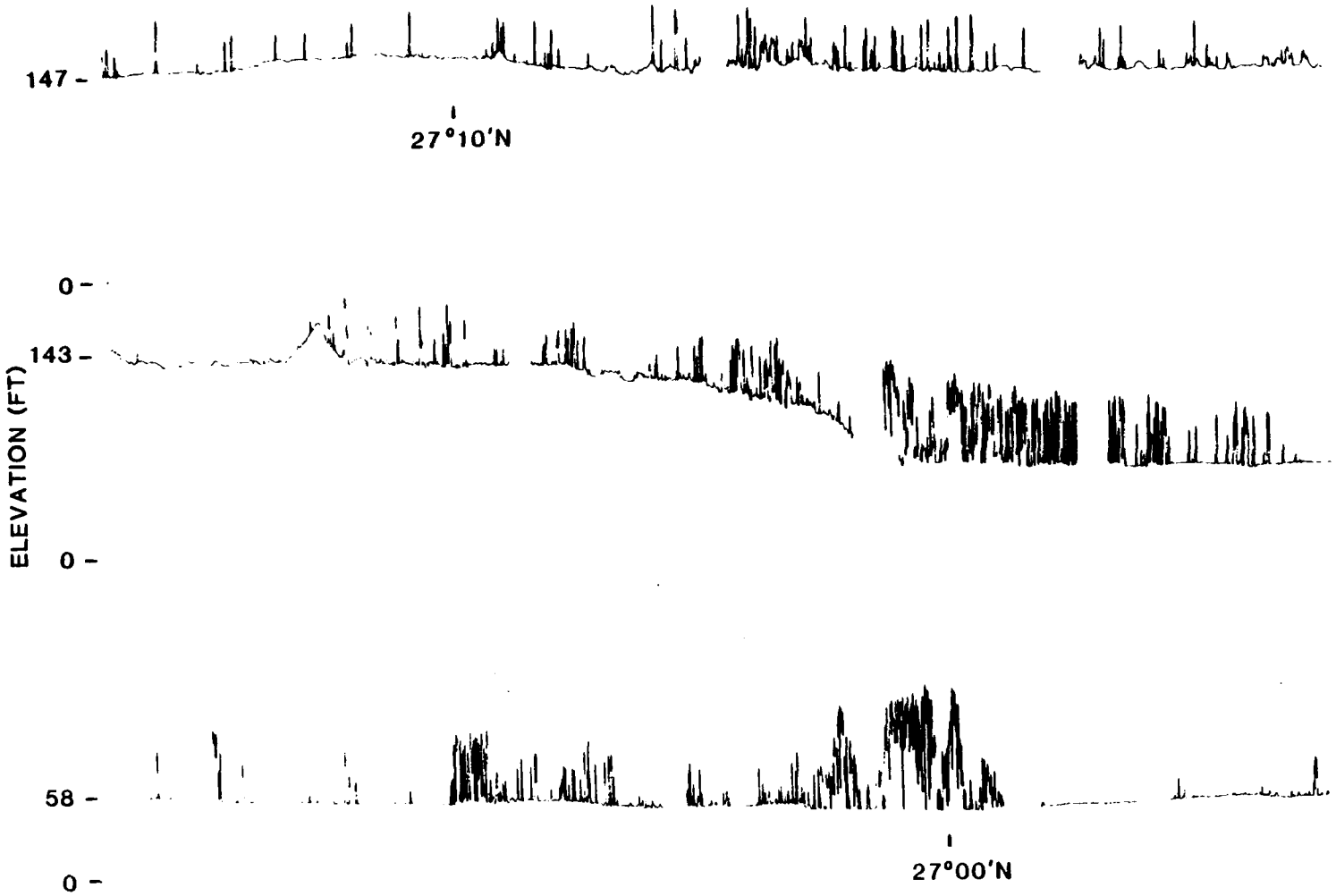


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

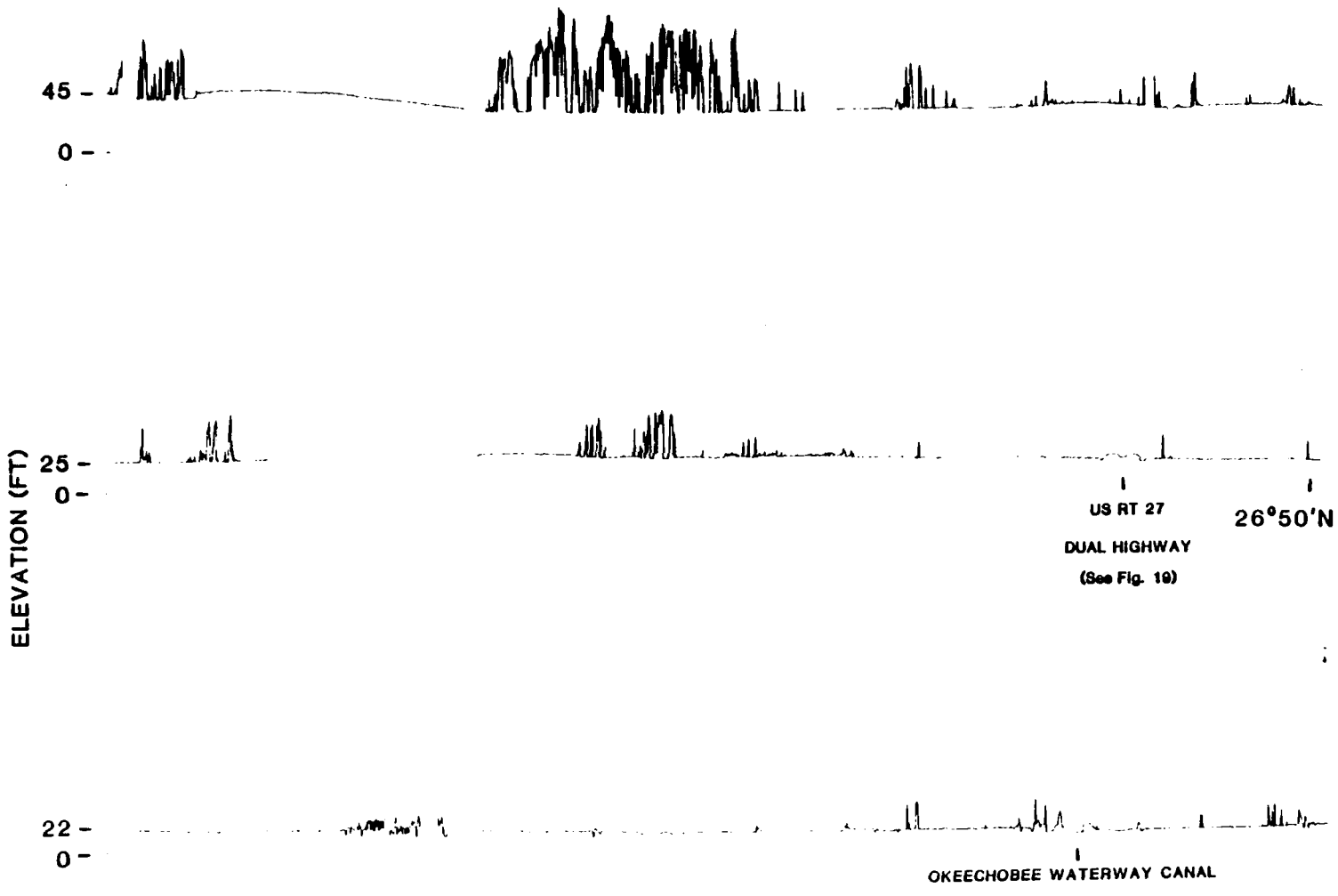


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

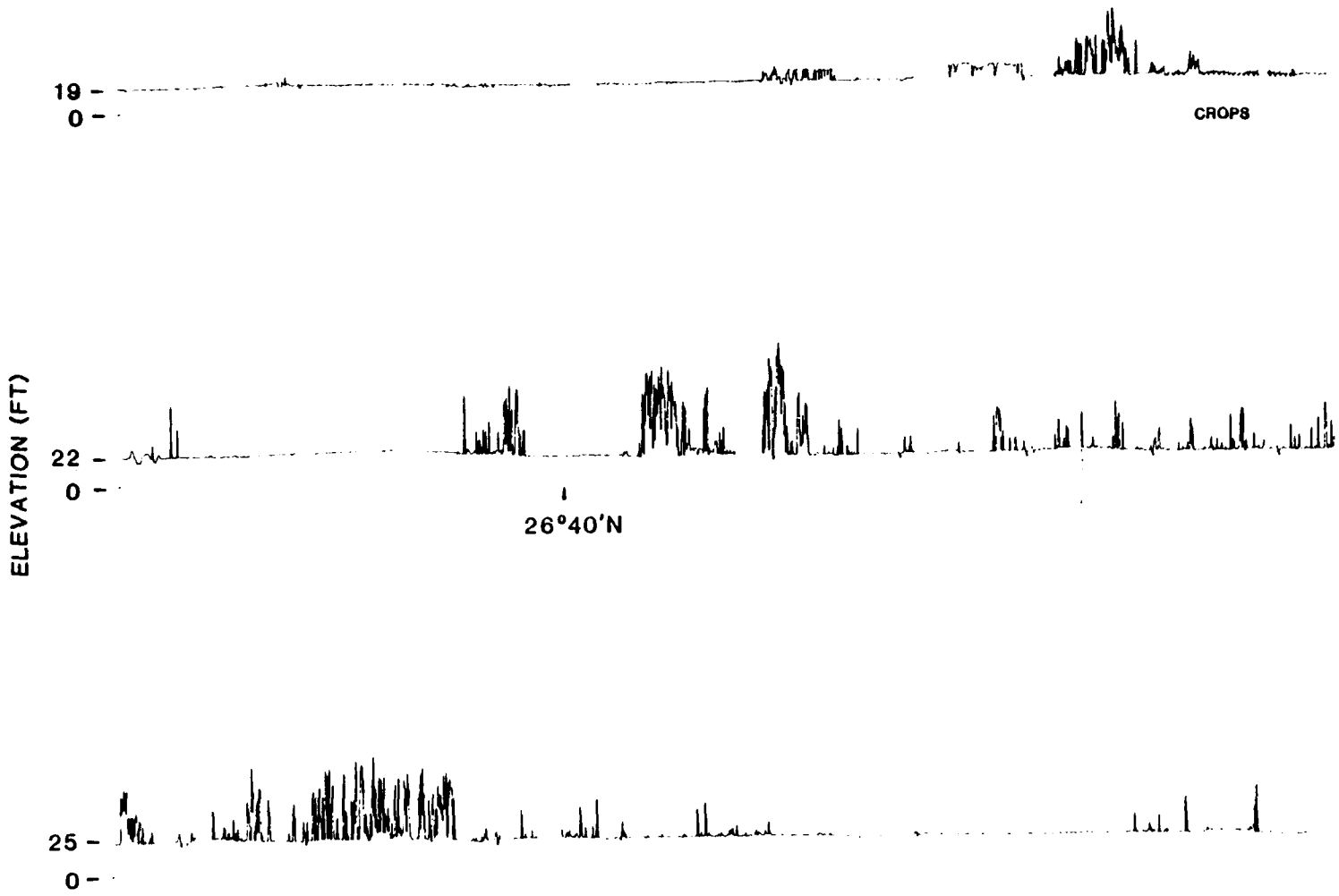


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

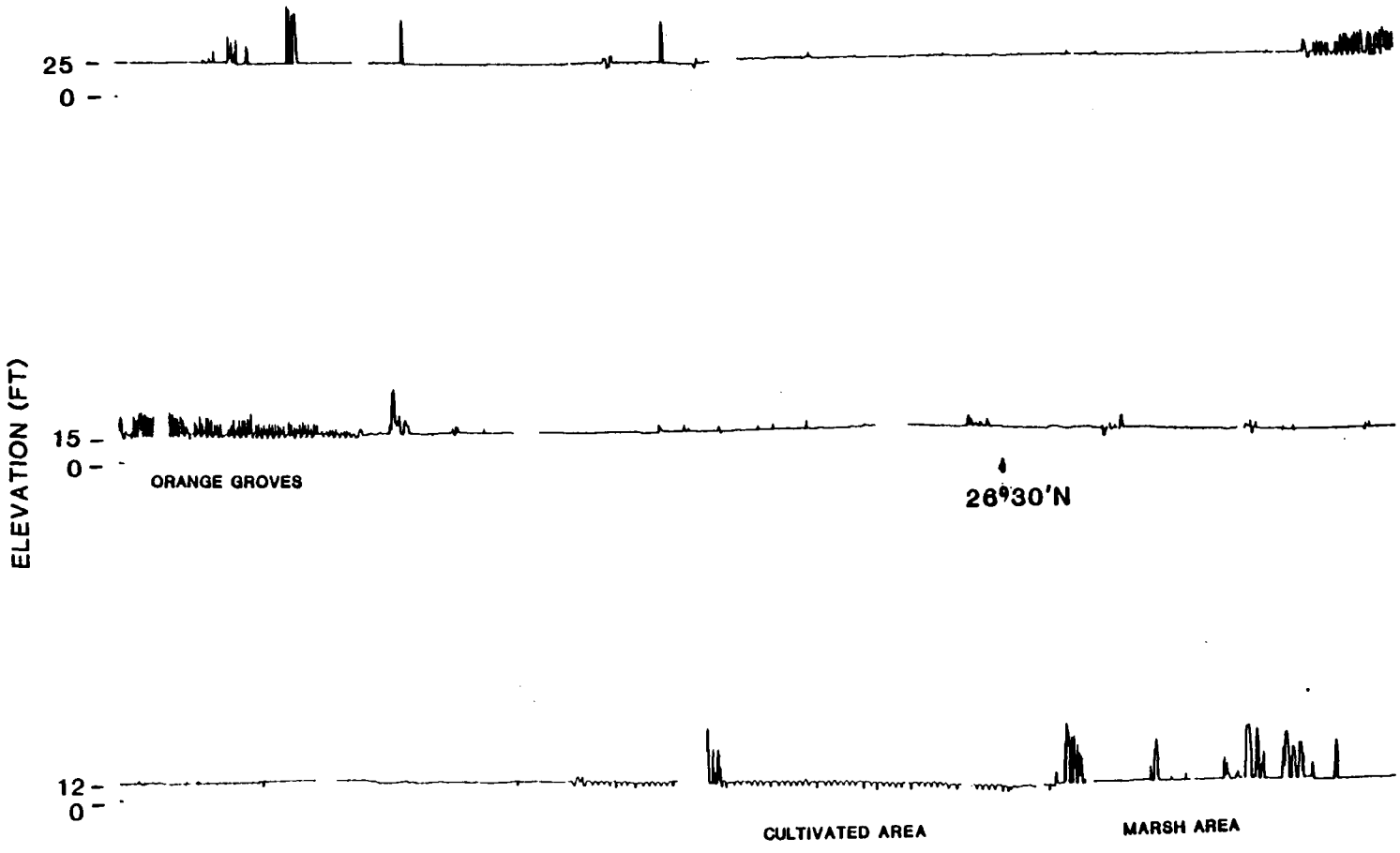


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

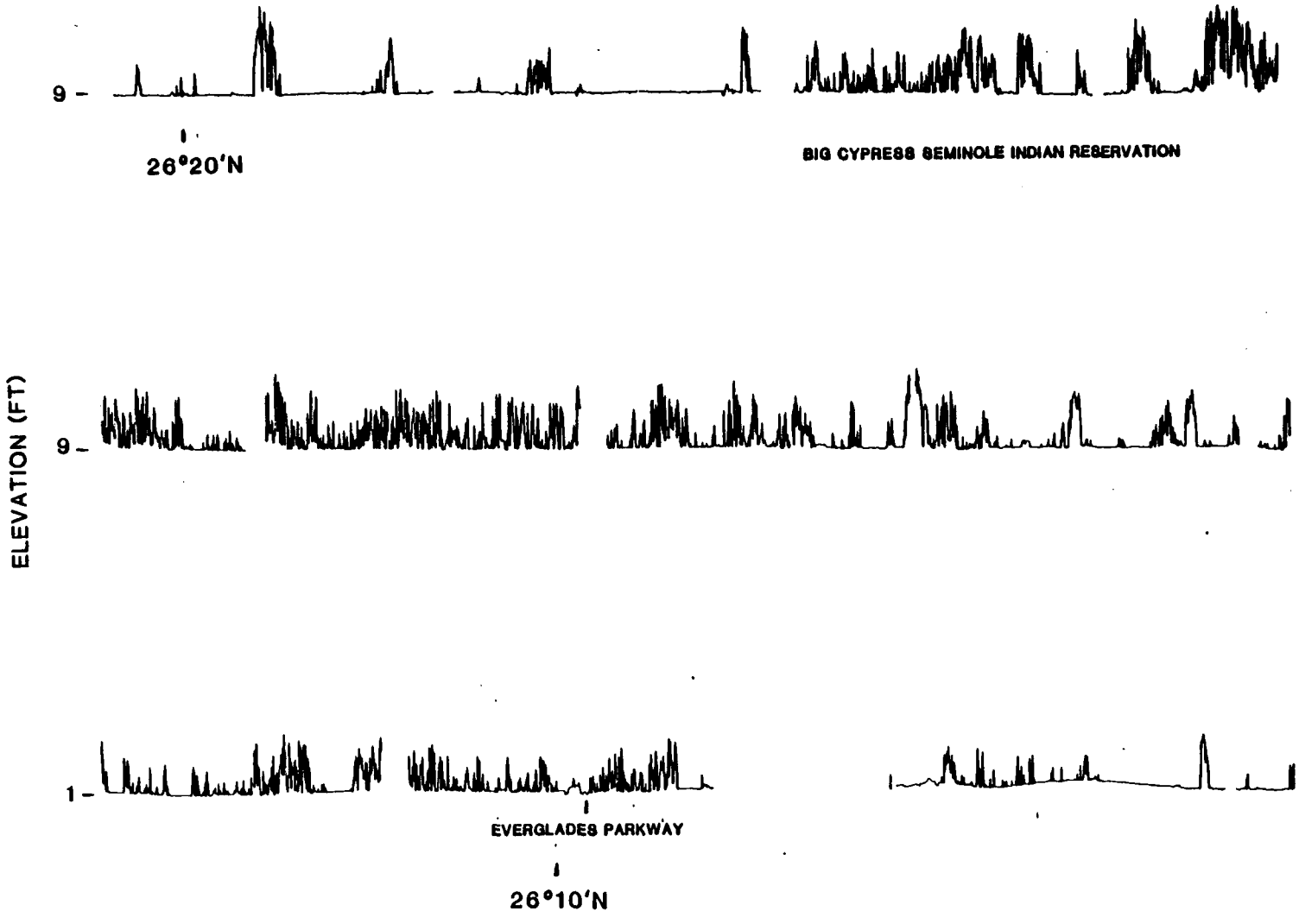


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

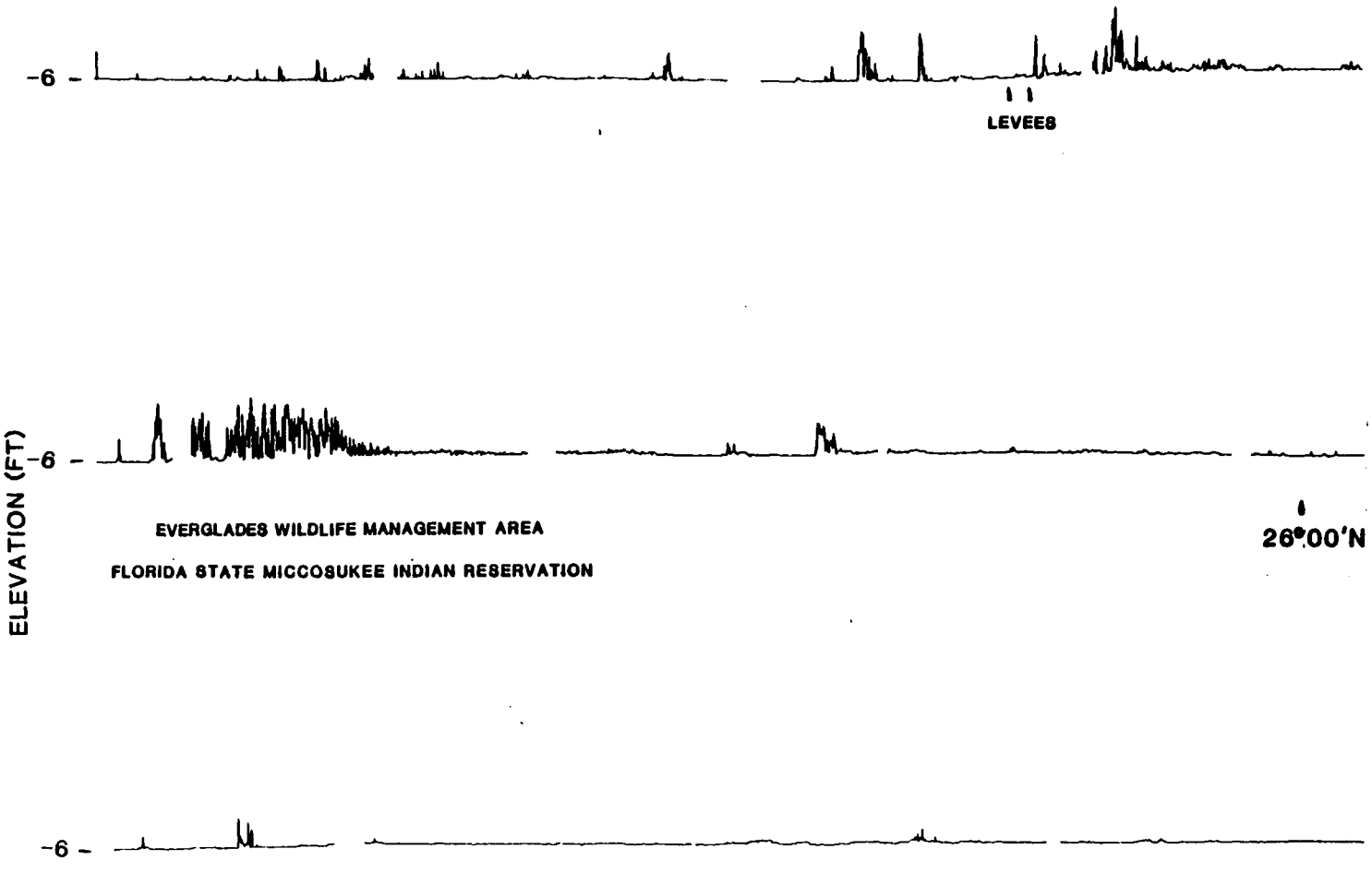


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

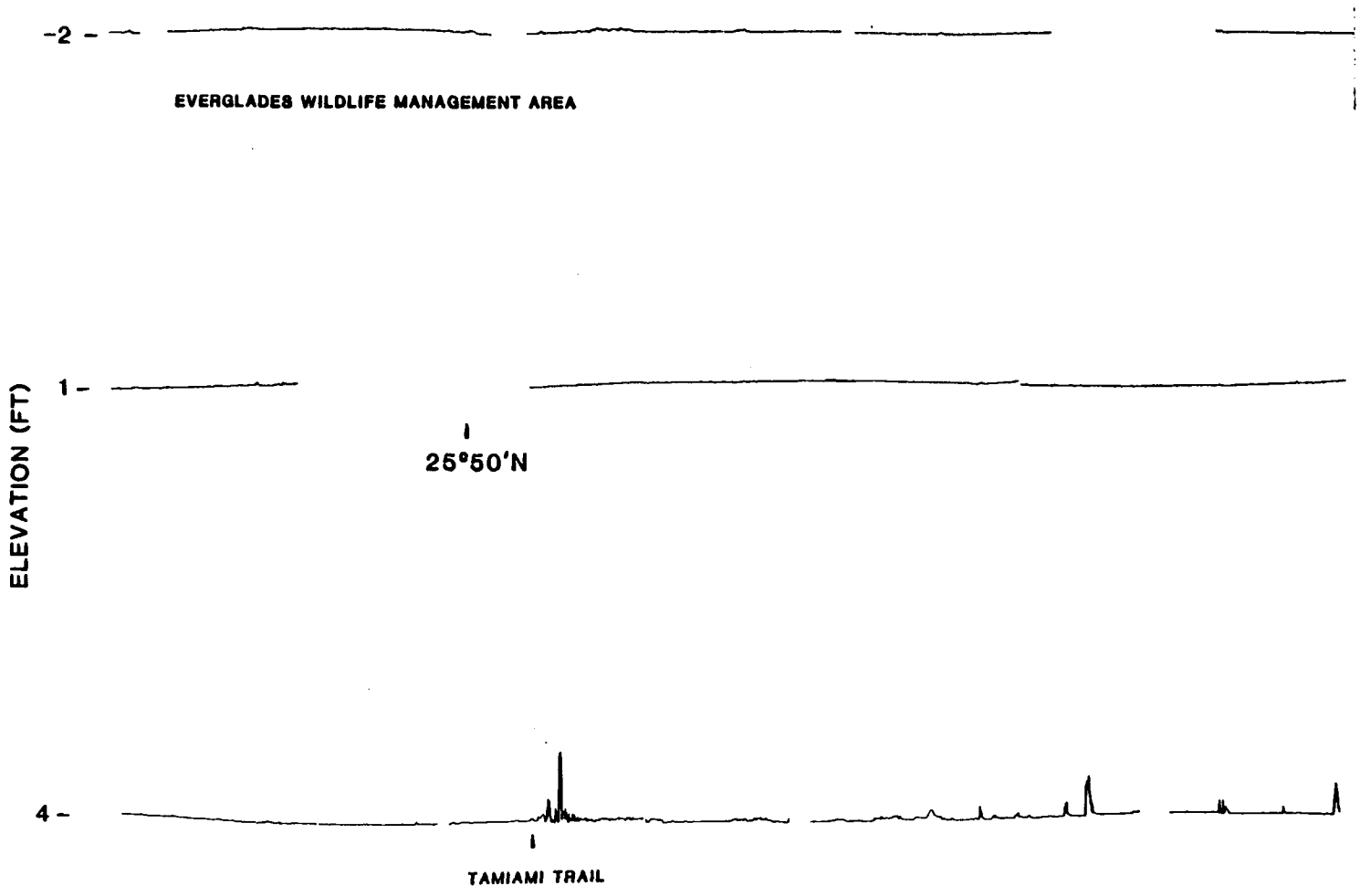


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

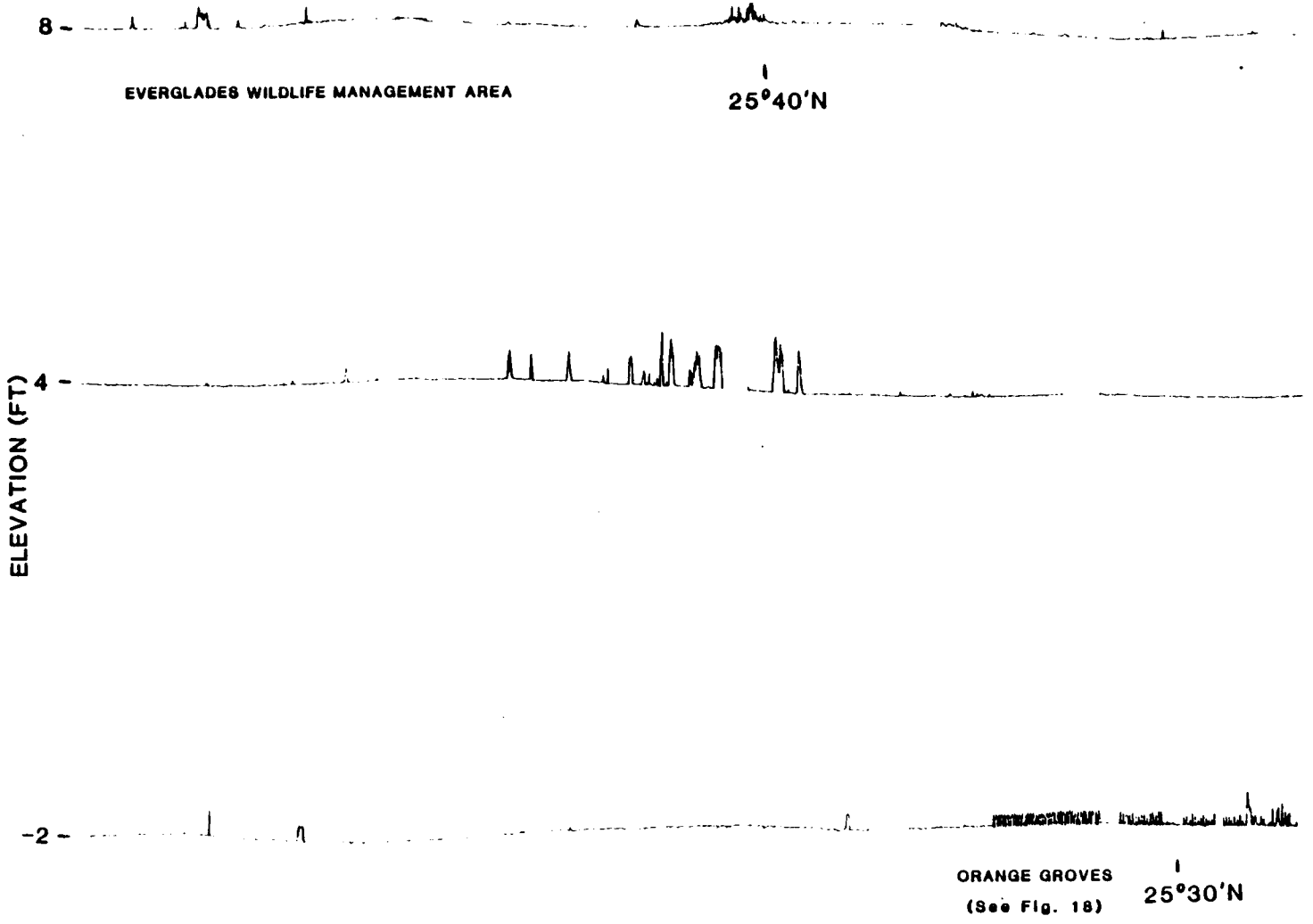


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

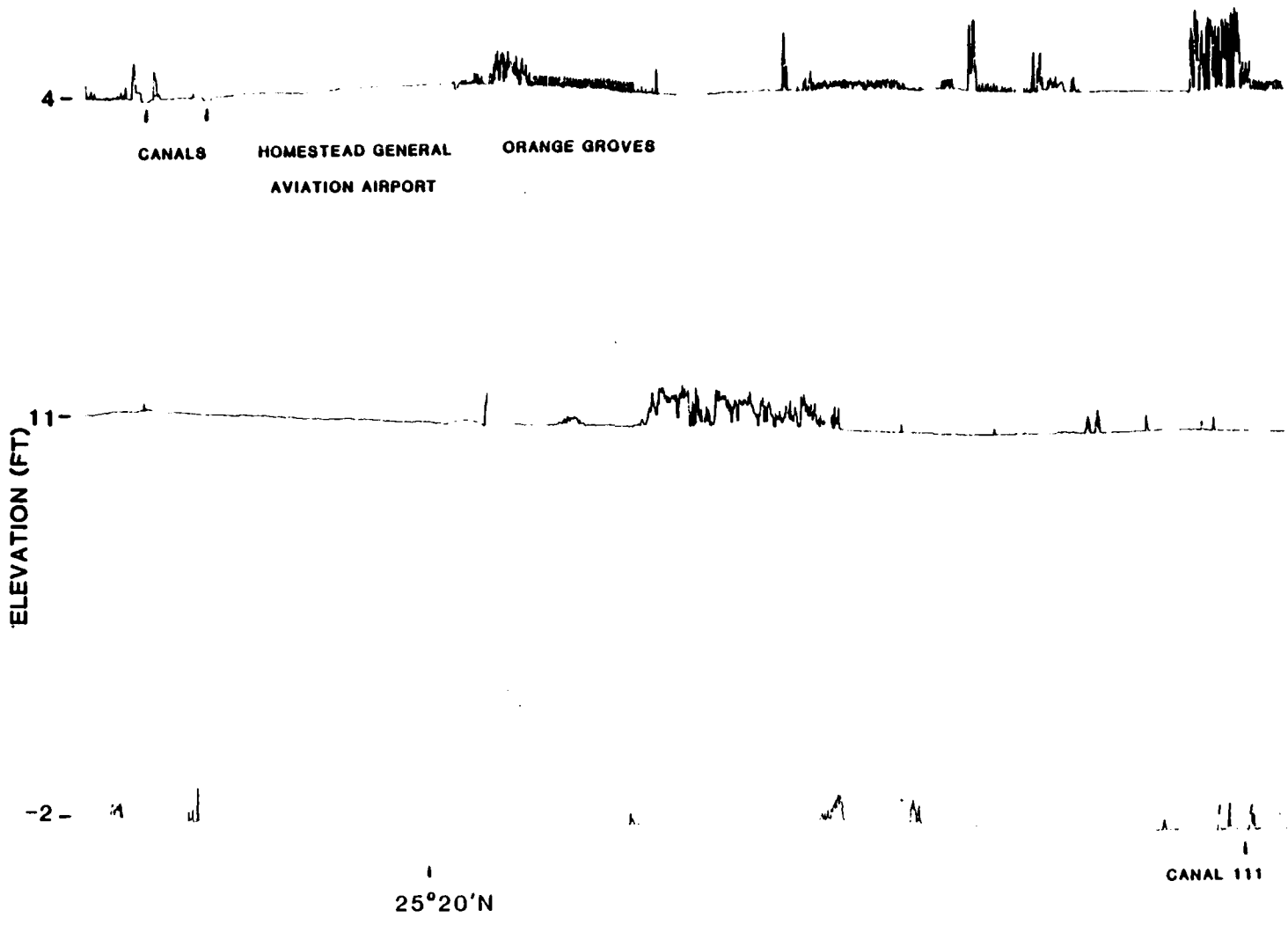


Figure 22 — (Continued) Laser profile along the entire south/north trackline over Florida

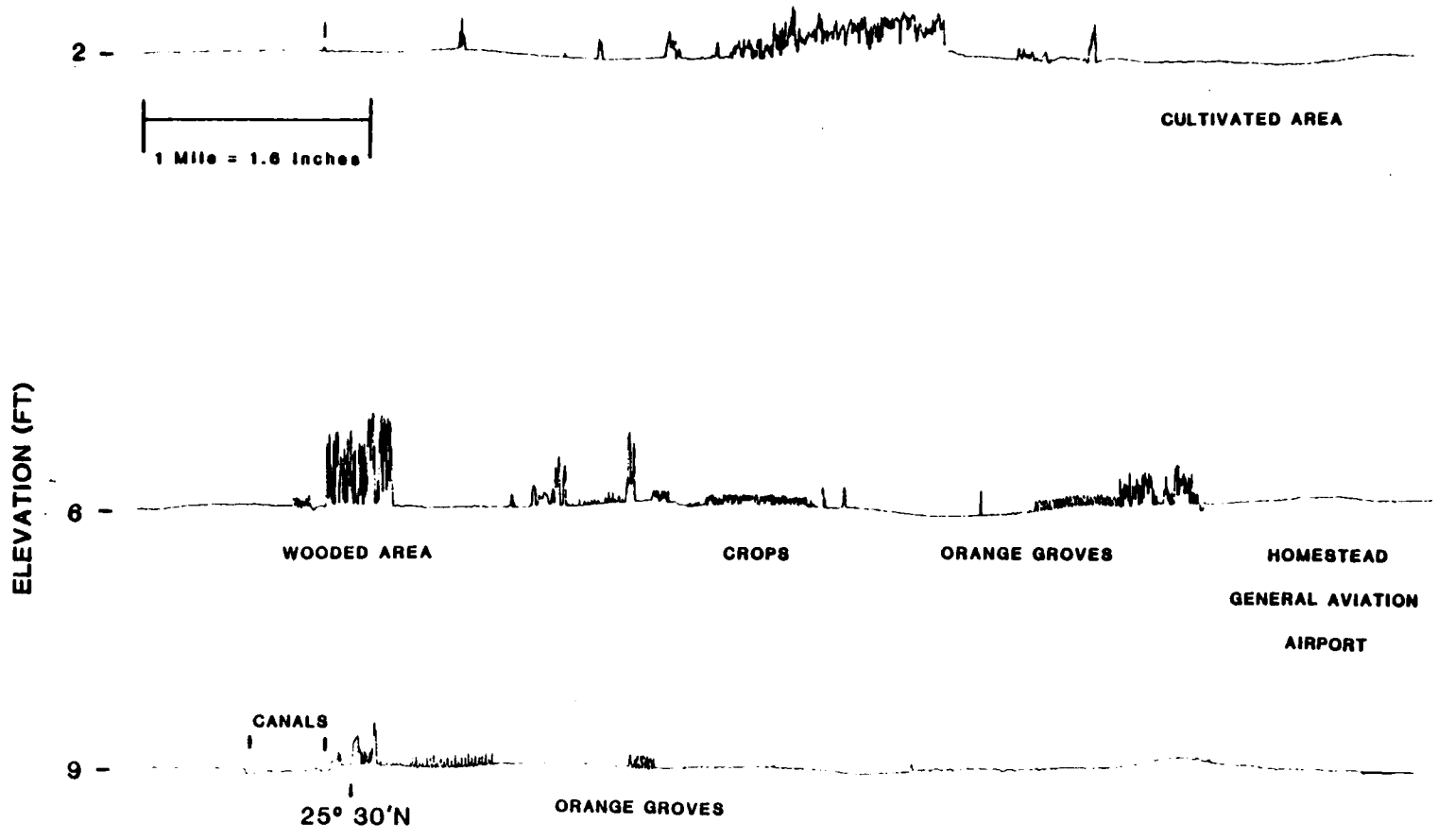


Figure 23. Laser profile along the entire south/north trackline over Florida.

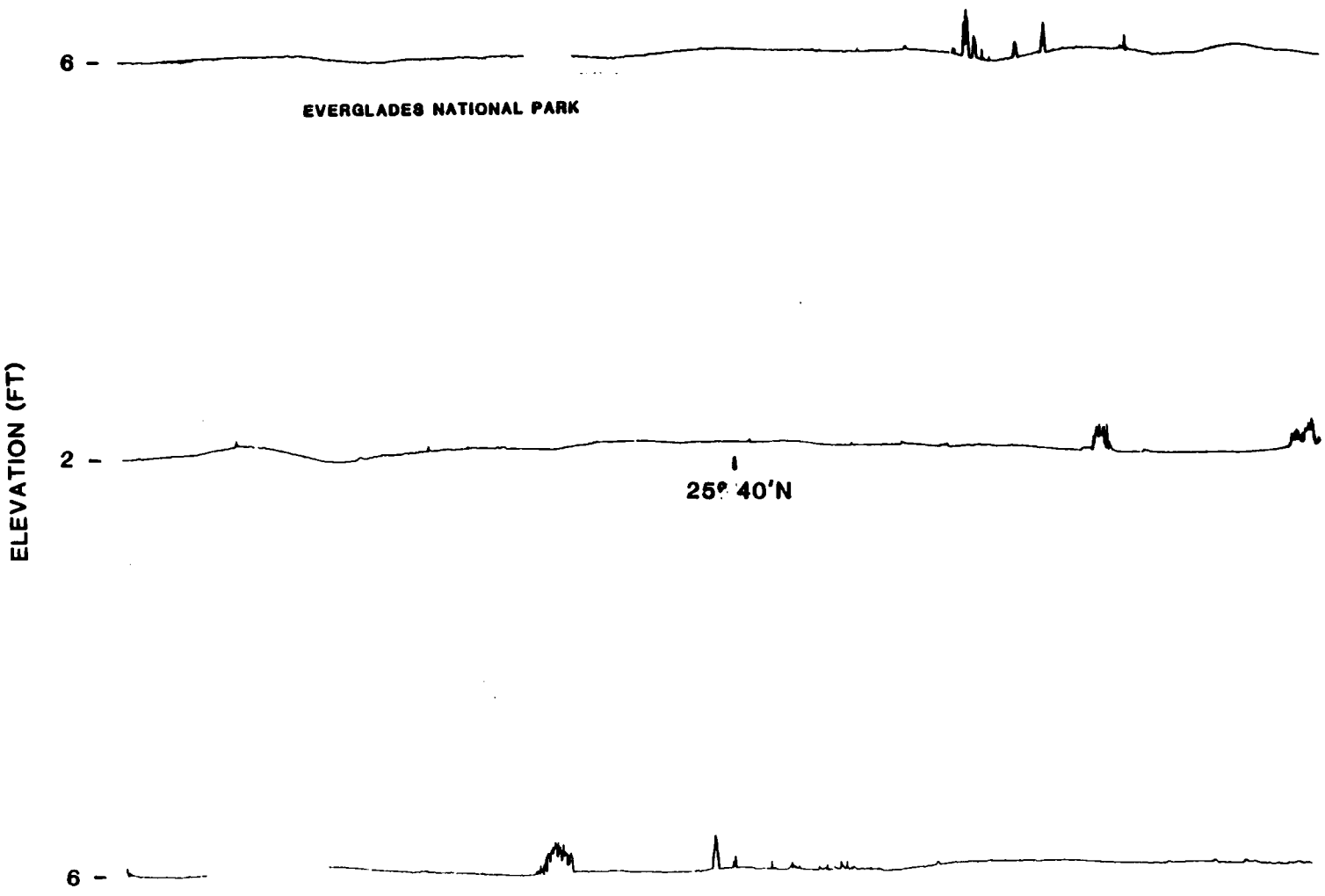


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

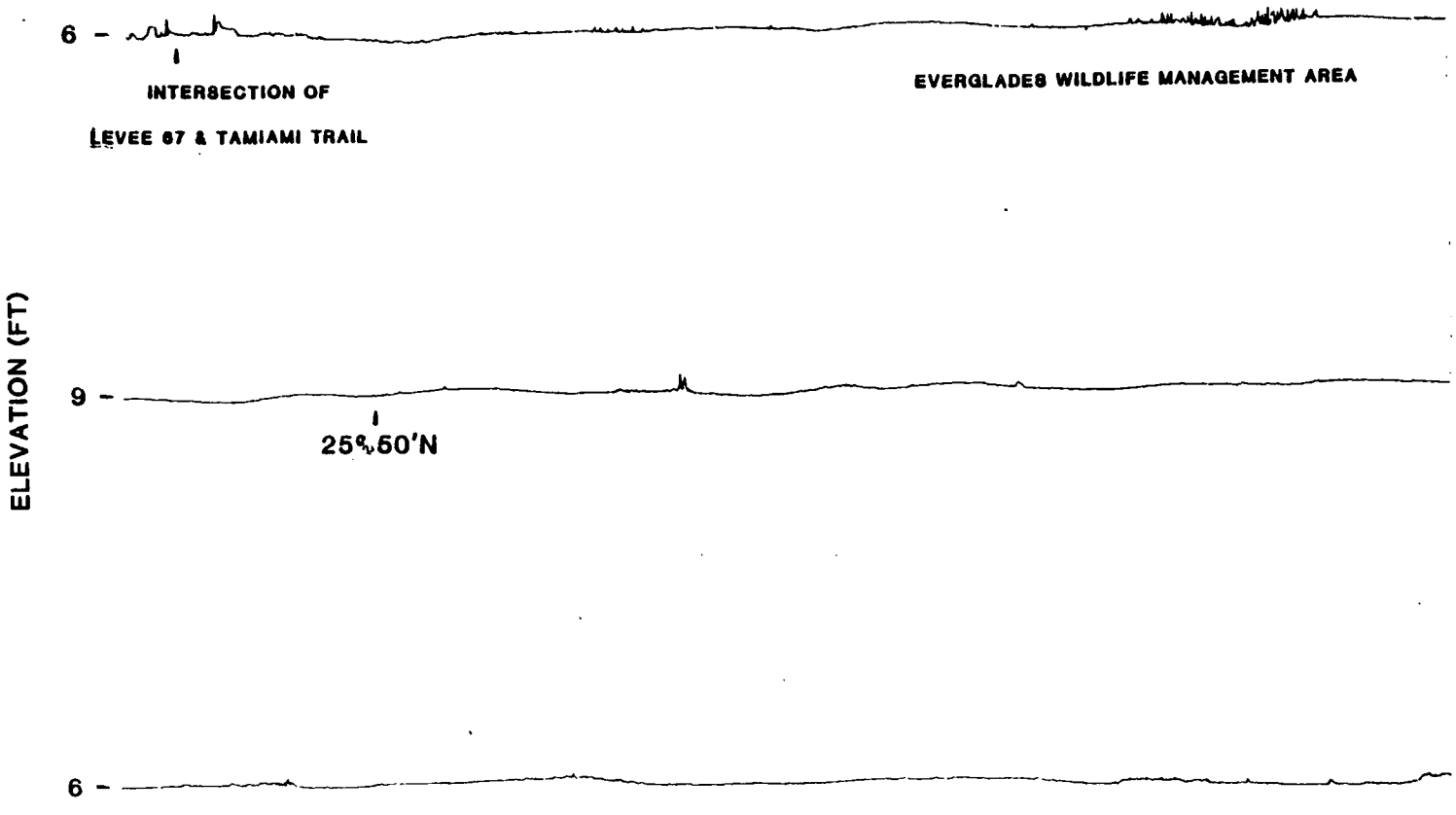


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

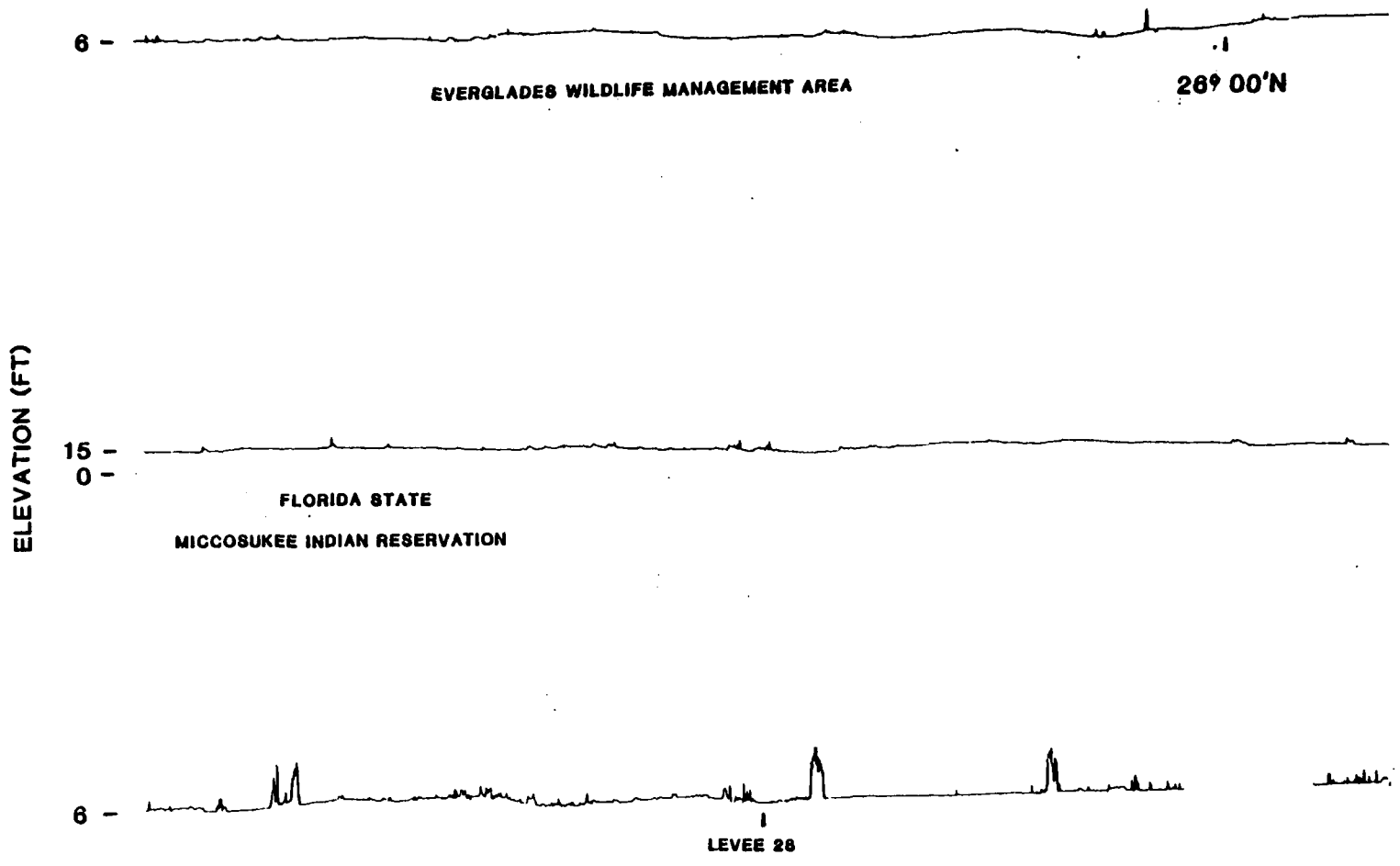


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

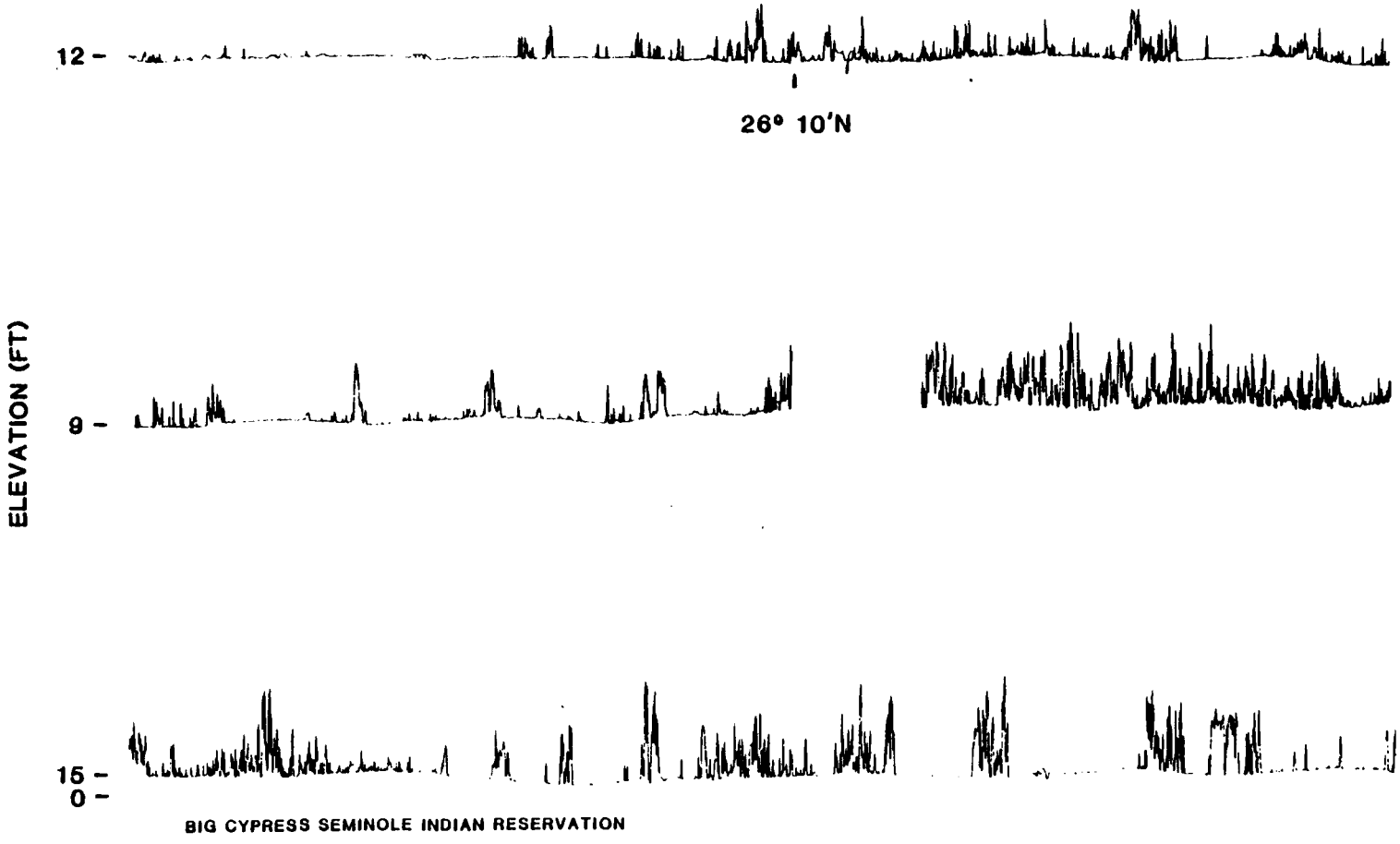


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

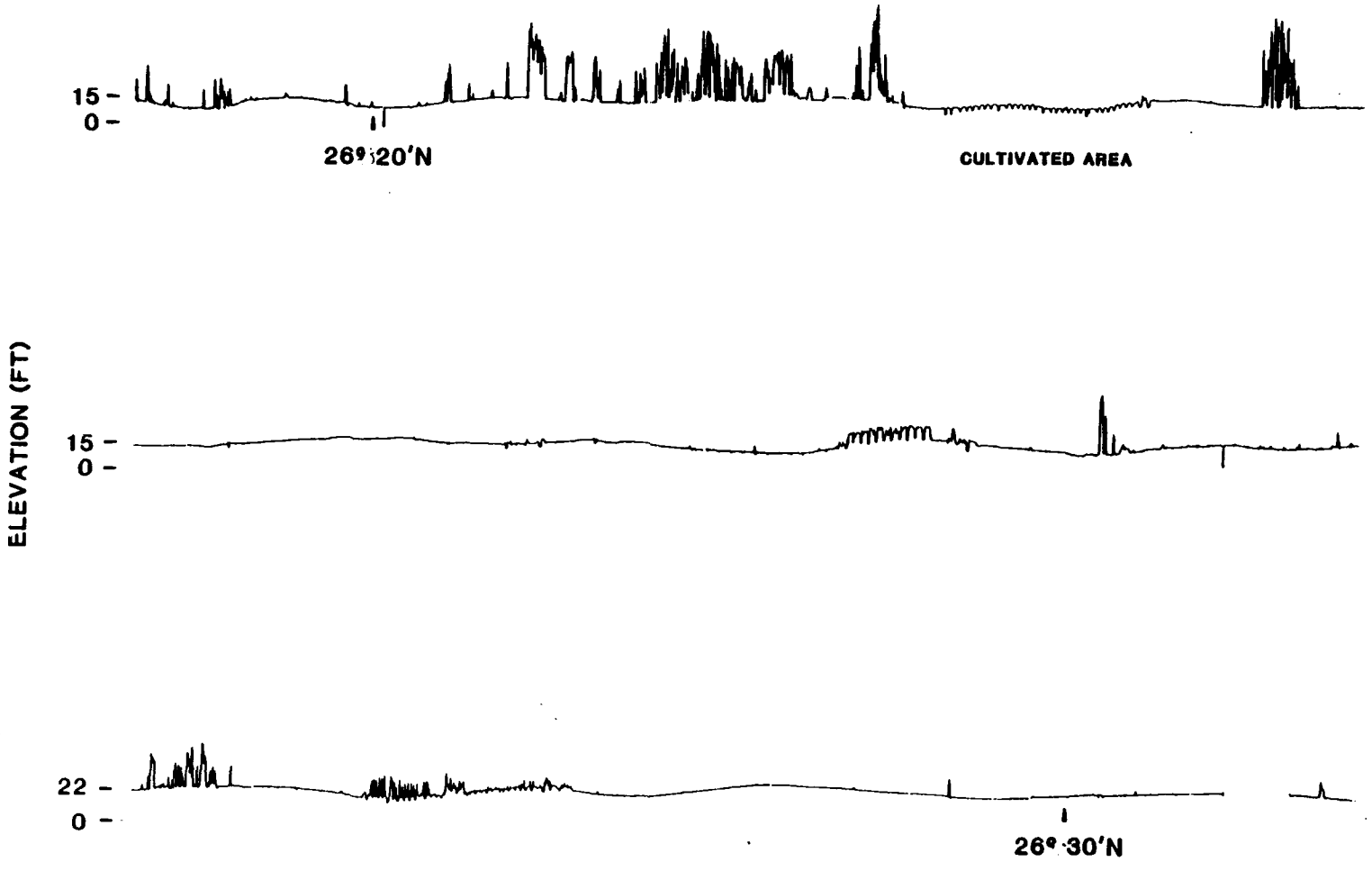


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

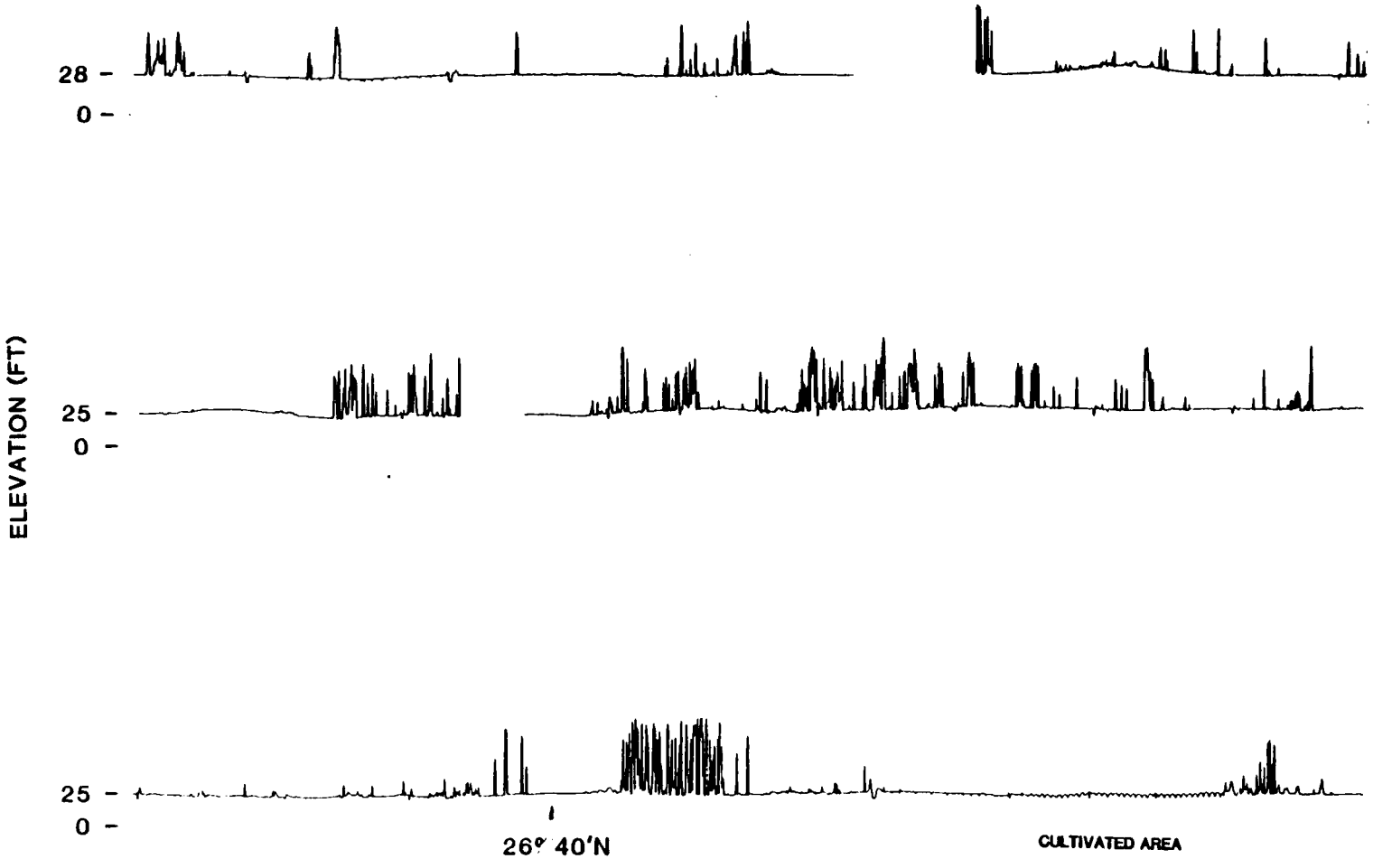


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

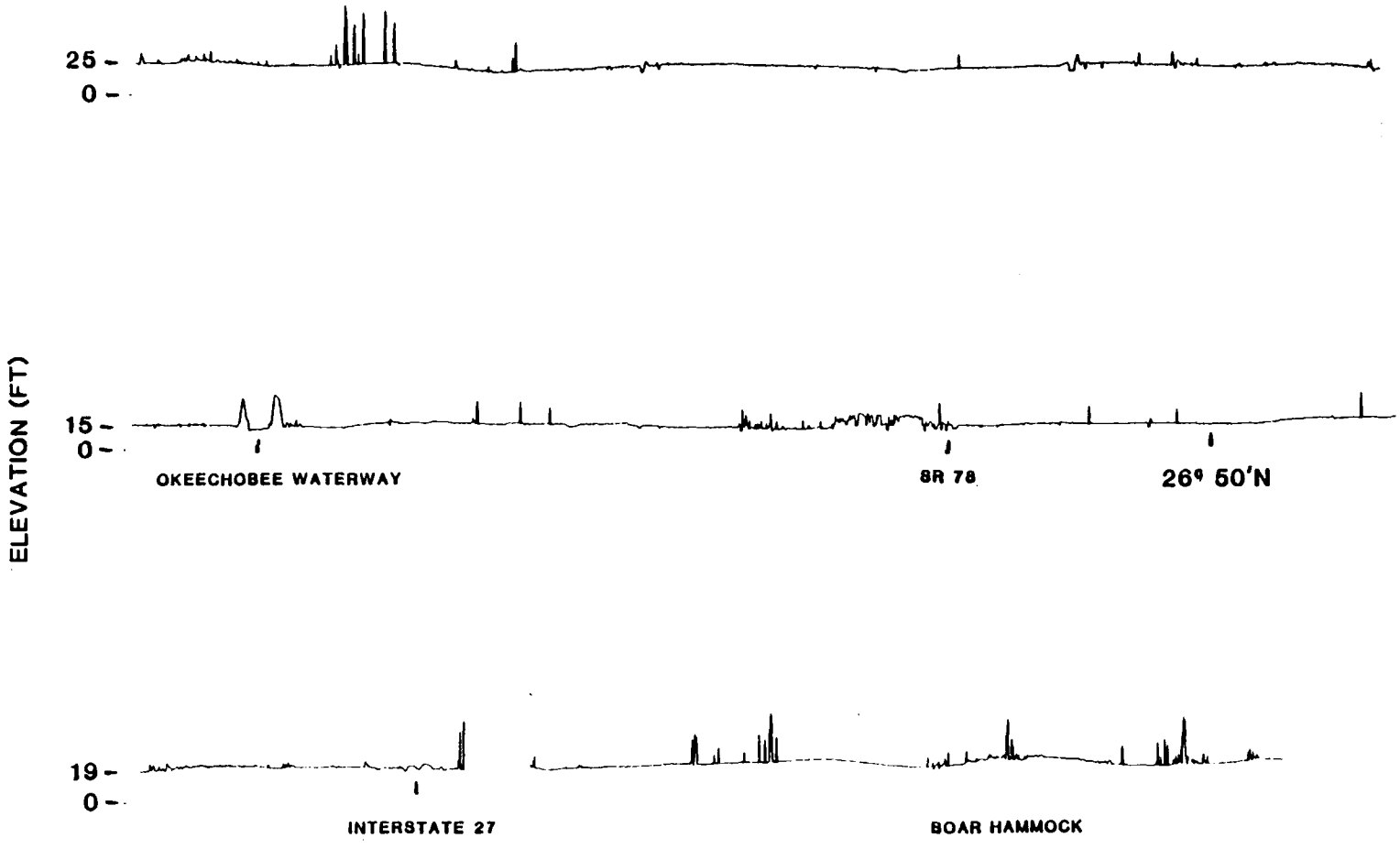


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

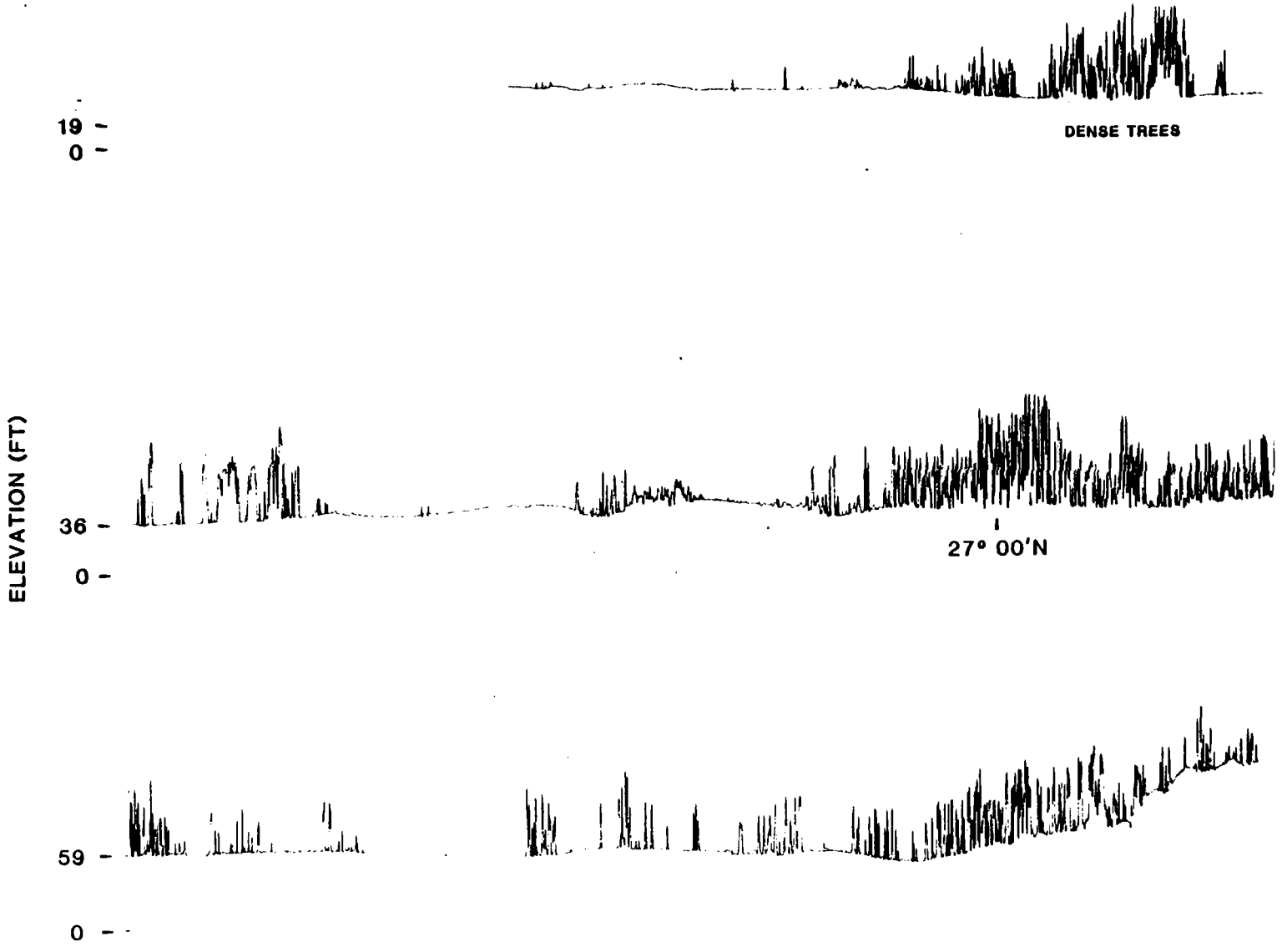


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

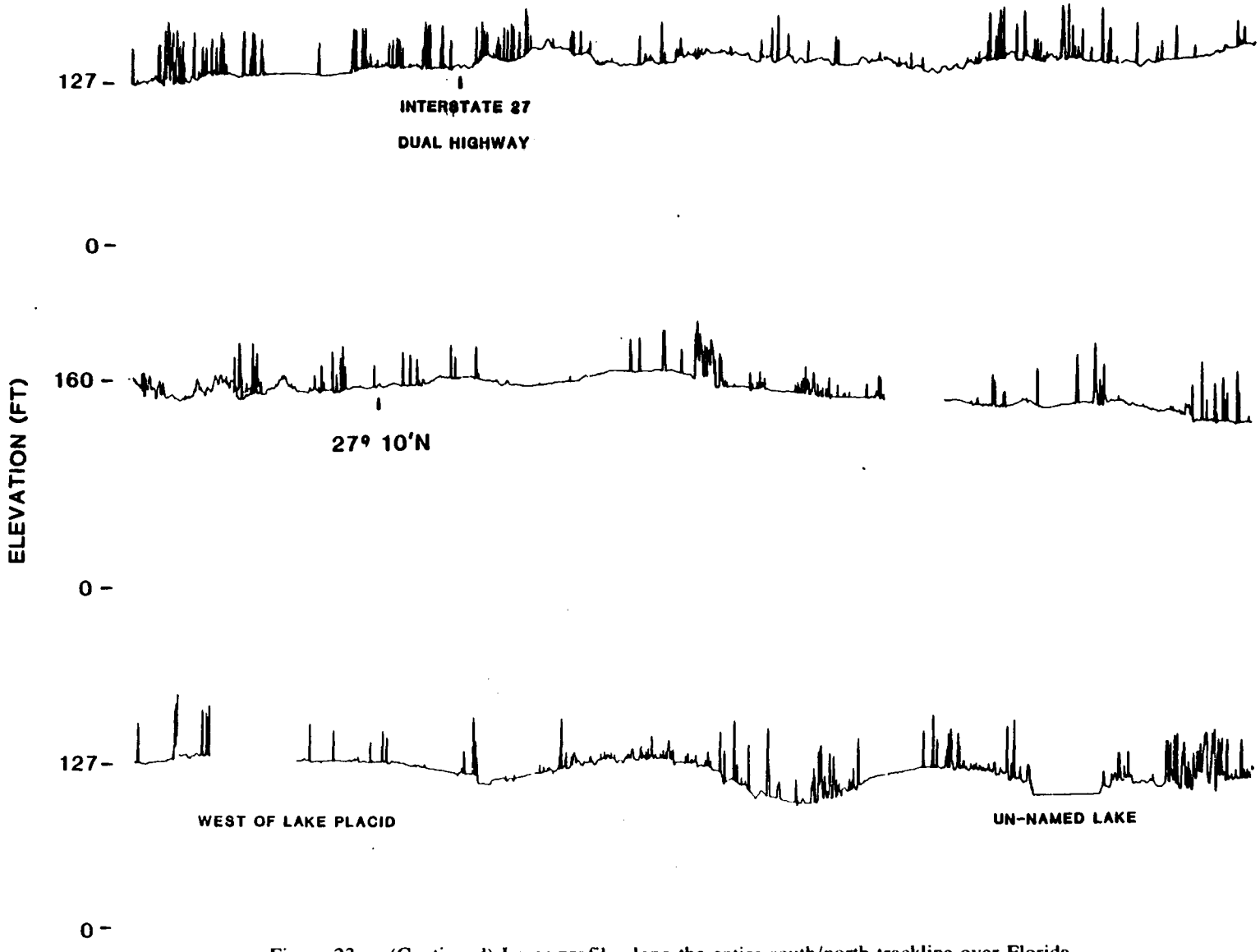


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

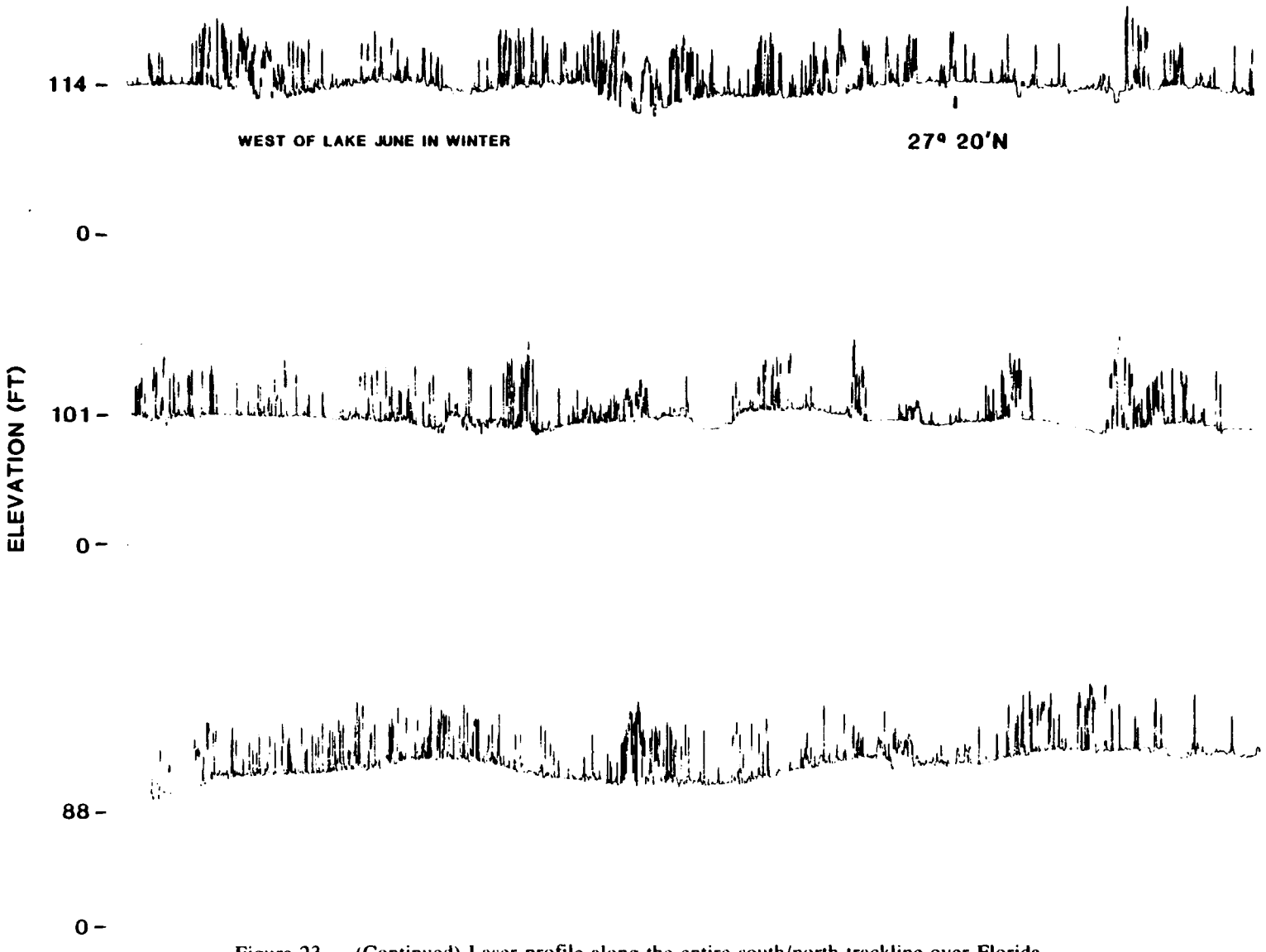


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

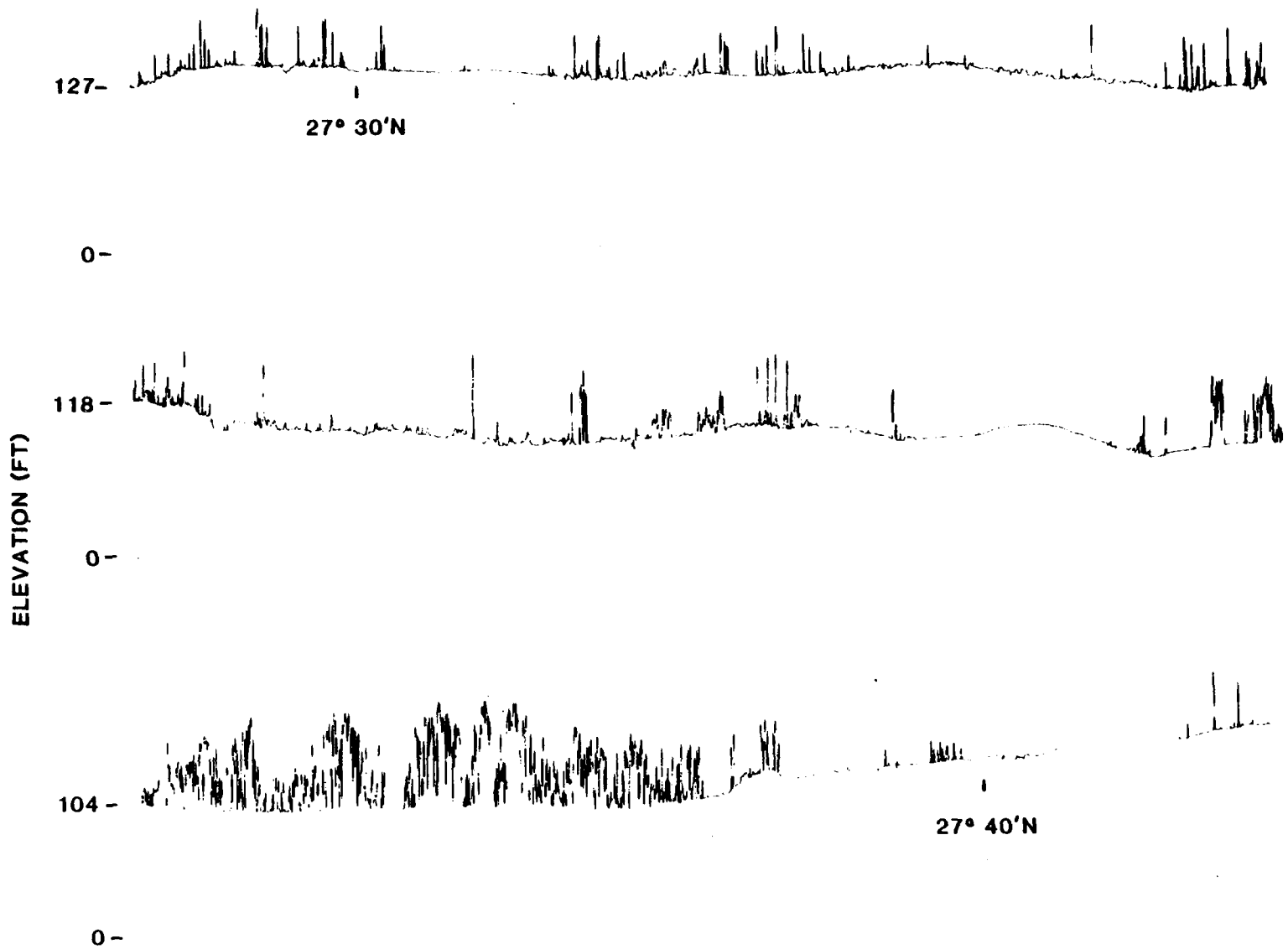


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

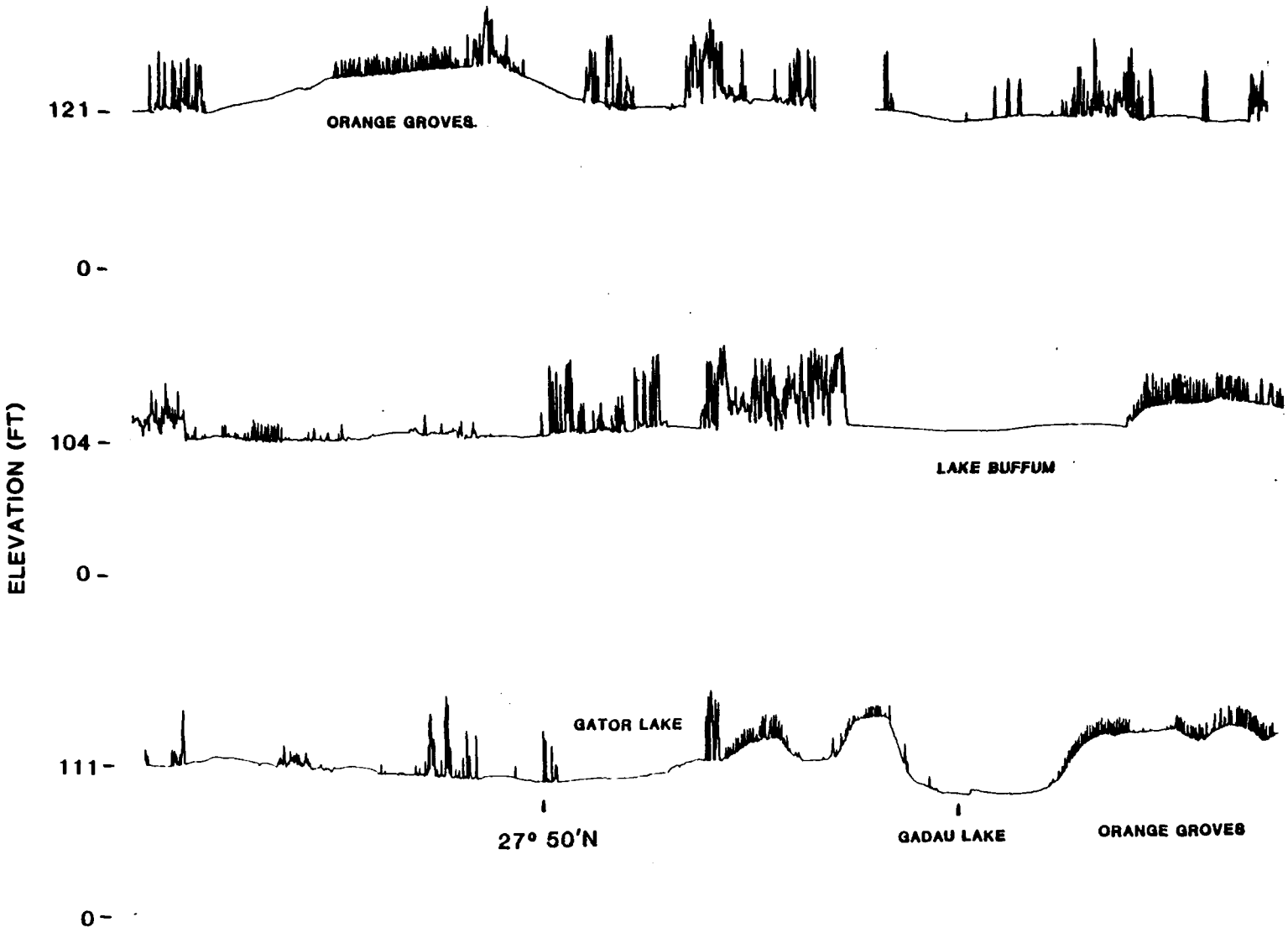


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

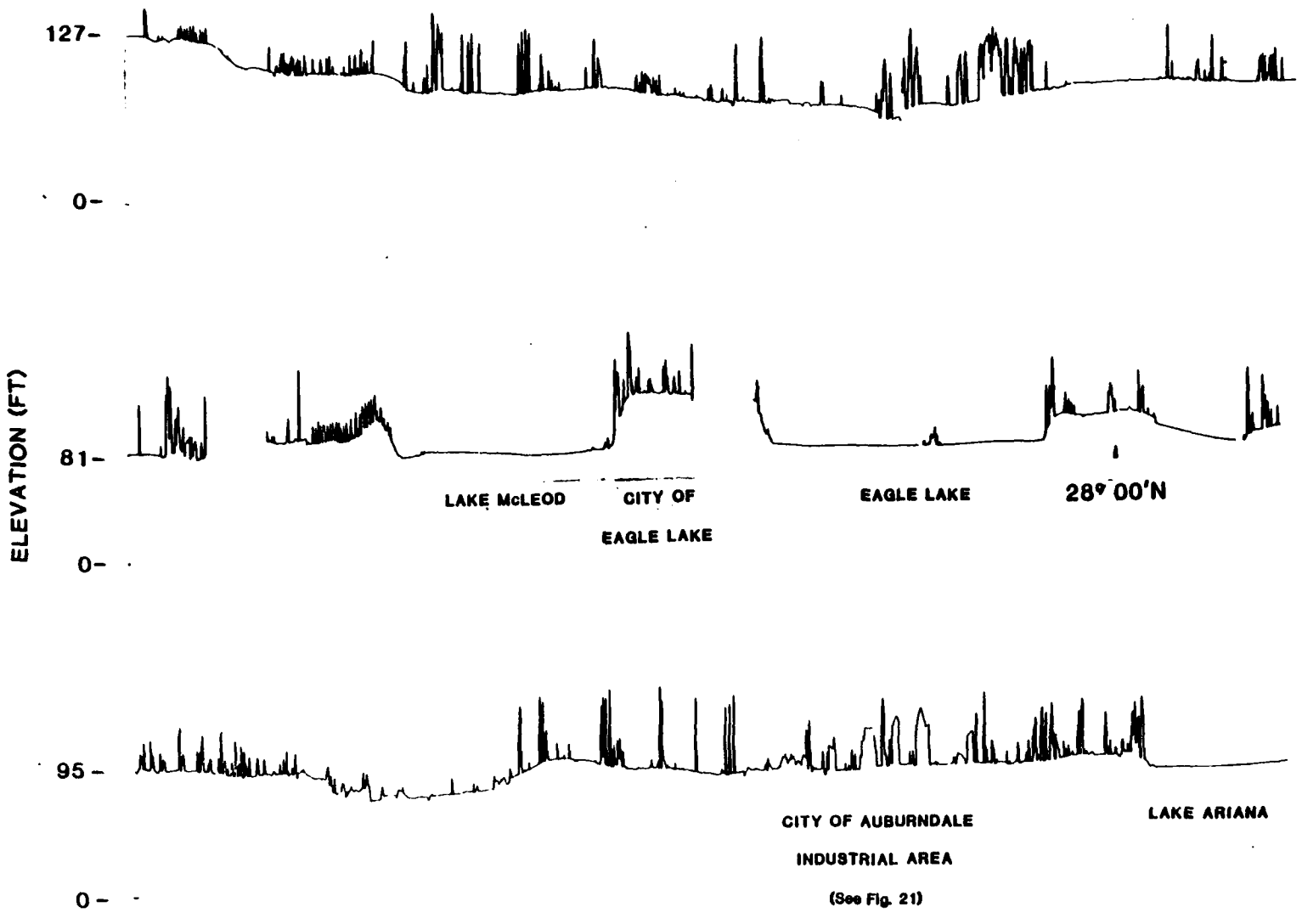


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

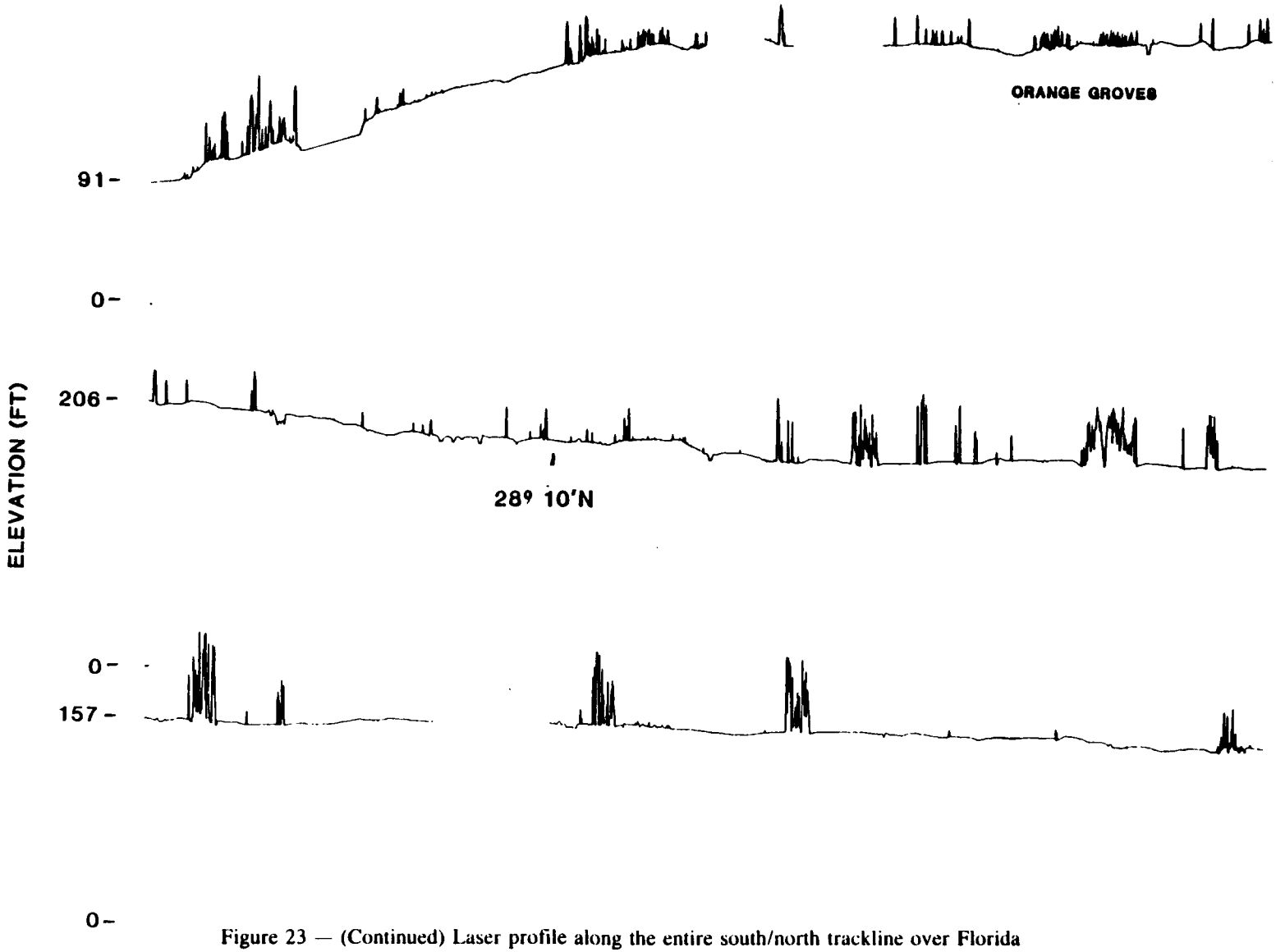


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

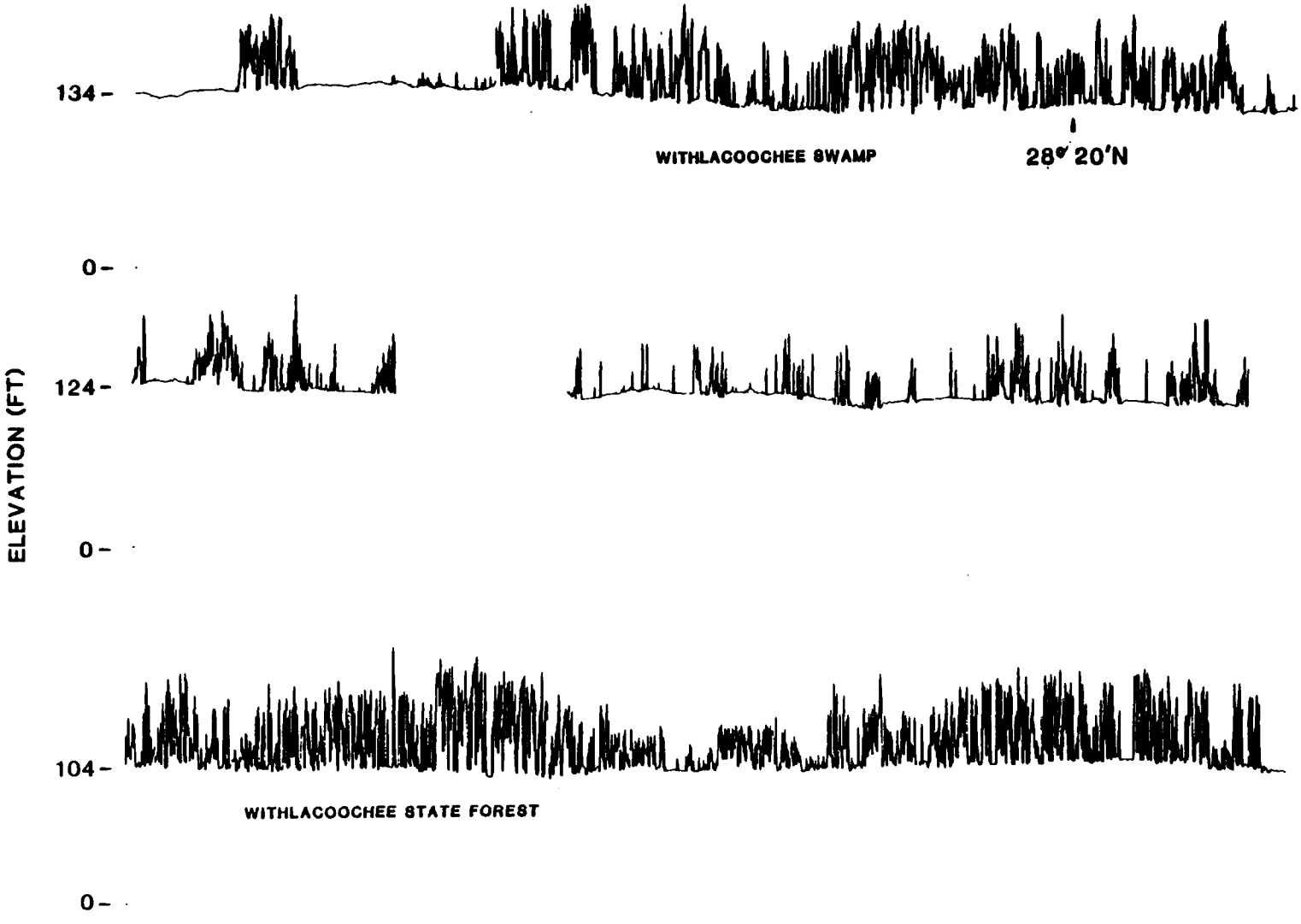


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

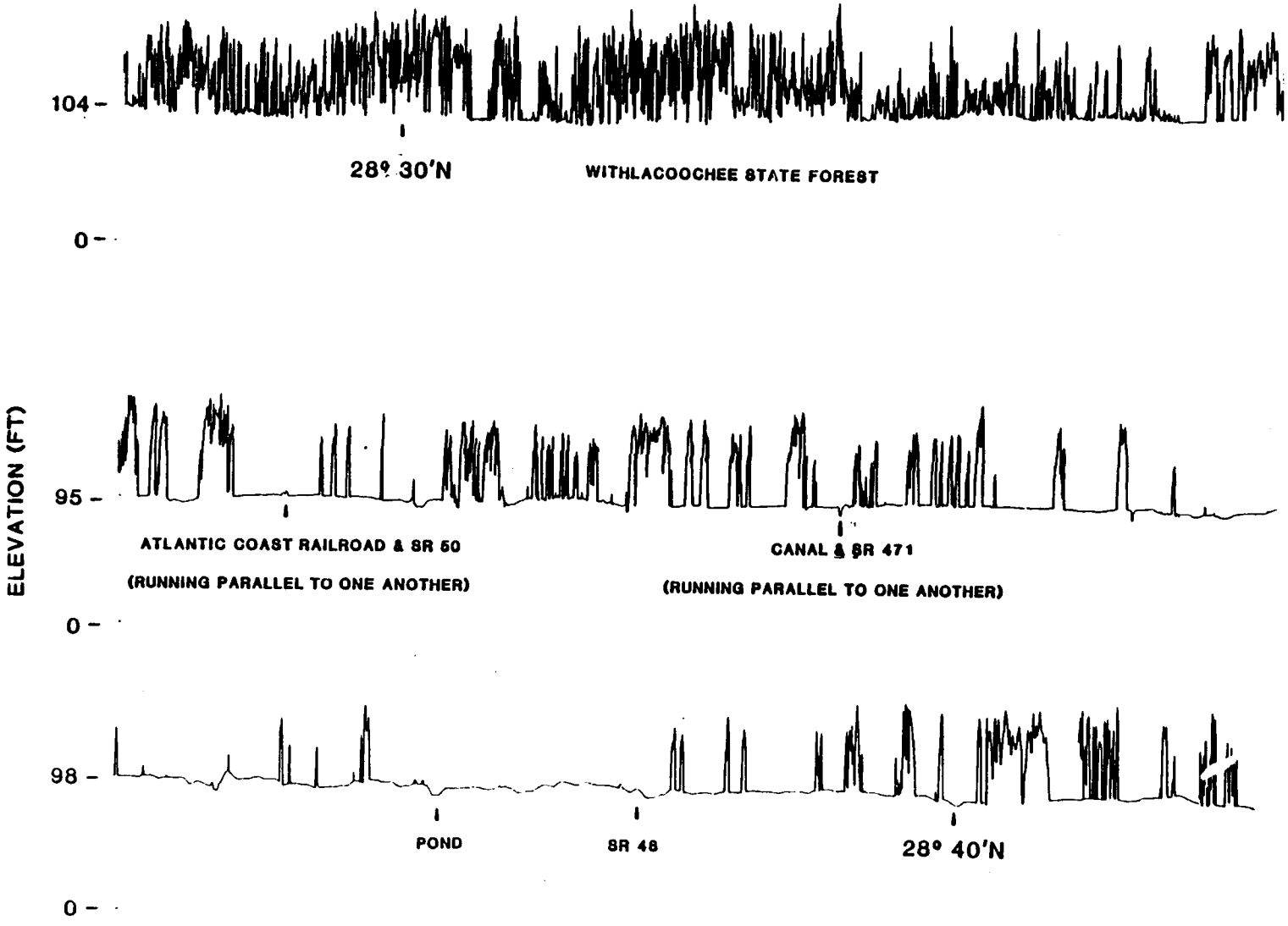


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

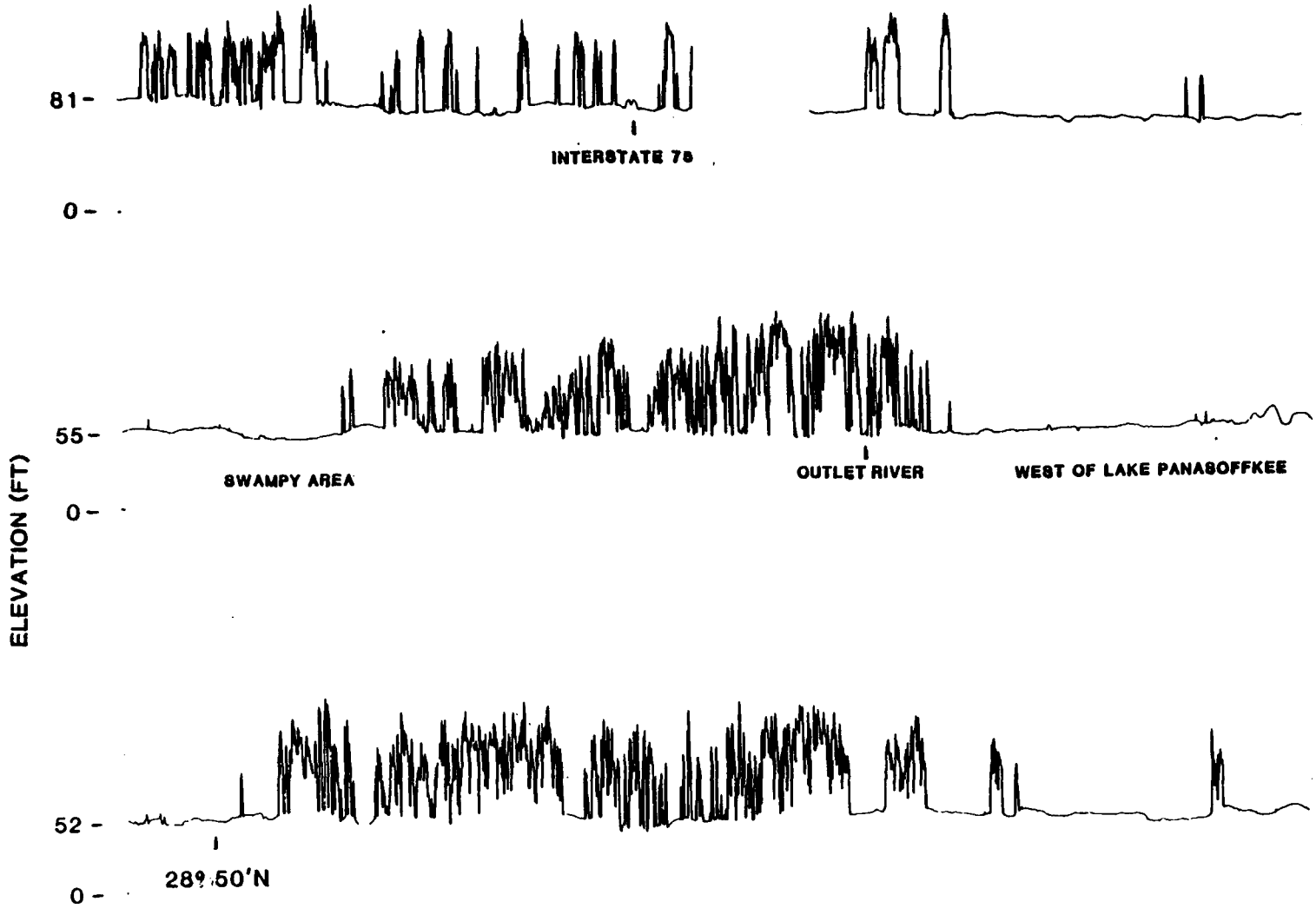


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

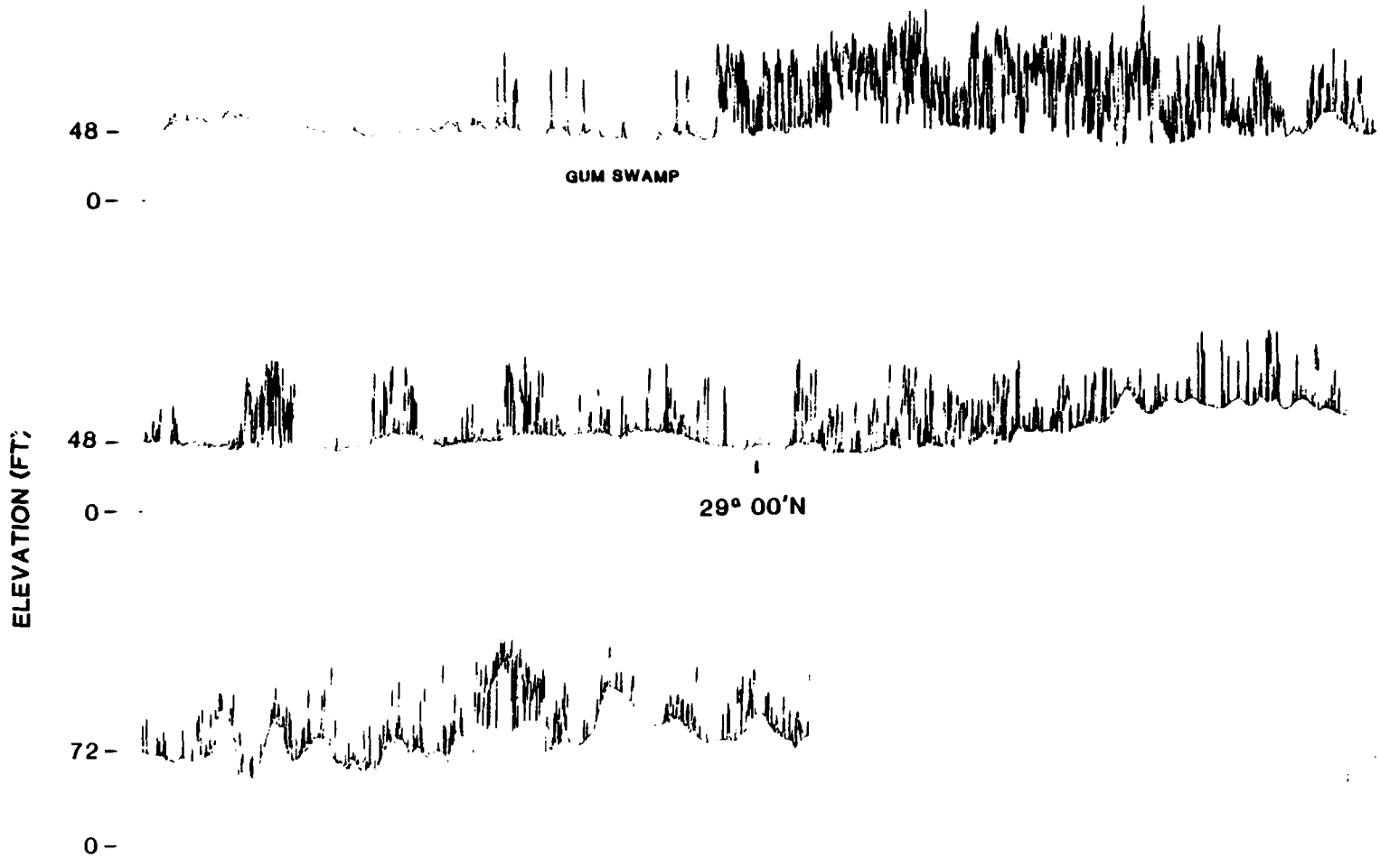


Figure 23 — (Continued) Laser profile along the entire south/north trackline over Florida

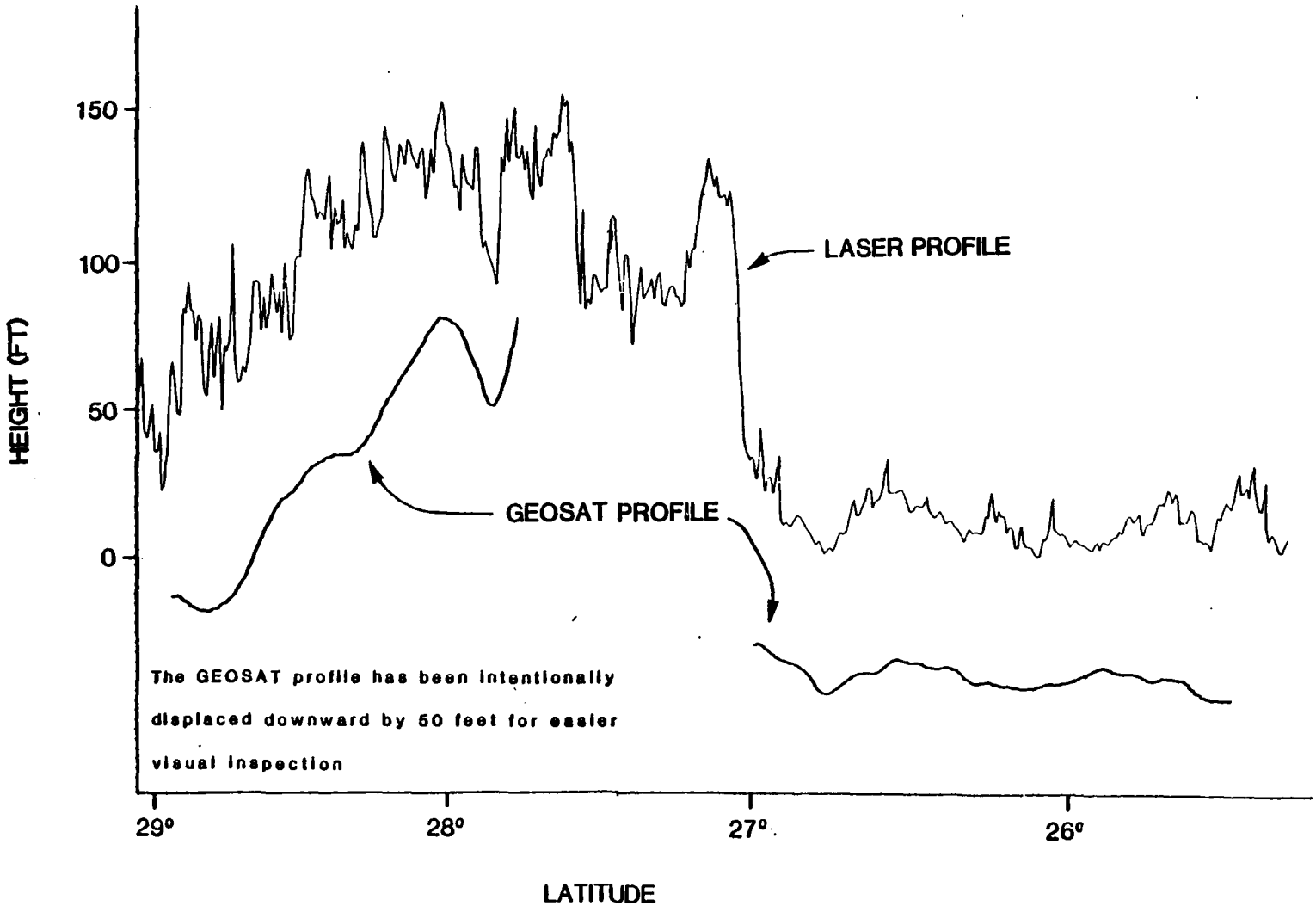


Figure 24. A comparison of the laser profile over Florida with a GEOSAT profile along the same trackline.